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SOIL AND MINERAL SUPPLEMENTS IN THE TREATMENT OF BUSH-SICKNESS

T. RIGG and H. O. ASKEW

(*Cawthron Institute, Nelson, New Zealand*)

In a previous publication [1] reference has been made to the occurrence of stock-ailment on certain pastures that are located on granite soils in the Glenhope district, Waimea County, Nelson, and the investigations there reported showed that the Glenhope ailment resembled closely the typical 'bush-sickness', described by Reid, Aston and others, which is associated with certain volcanic soils in the central territory of the North Island of New Zealand.

Sheep affected with ailment at Glenhope are anaemic in appearance; chemical analyses of blood samples show a great deficiency of total solids and of iron; affected sheep respond to a drench of ferric ammonium citrate, which has been shown by Aston [2] to give good results in the treatment of bush-sickness in the North Island.

The analyses of a series of pasture samples taken from three soil types at Glenhope, two of which were unaffected with bush-sickness, showed that the average iron-content of the healthy pastures was frequently little better than that of the unhealthy pasture. The average iron-content of a series of samples of the Moutere Hills pasture was almost identical with that of the unhealthy pasture located on the Glenhope granite soil. In an attempt to explain this anomaly, it was suggested [1] that the soil-contaminating pasture provided a supply of iron which was valuable to stock. Analyses showed that the soil of Moutere Hills contained seven times more iron, soluble in 5 per cent. oxalic acid, than the affected granite soil. On the assumption of even 0·4 per cent. soil contamination of the green pasture, sheep on the Moutere Hills soil would obtain three and one-half times more iron in their food than sheep grazing the affected granite pastures.

Certain confirmatory evidence of the valuable property of soil in preventing the appearance of bush-sickness and allied ailments was mentioned in the publication referred to [1], in the experiment of Gilruth [3] in New Zealand, and in the observations of Hogg [4] on the 'pining' disease of the Cheviots, Scotland.

With a view to securing further information concerning the value of soil and other iron compounds in overcoming bush-sickness, a series of field trials was initiated at Glenhope in the spring of 1931 and continued during the 1932 season.

Experimental

During the first season of the experiments, 'licks' of Moutere Hills soil and of limonite obtained from Onekaka were tried. During the first half of the season, favourable progress of the sheep on the 'lick' fields was noticed in comparison with the control sheep not supplied with licks. During the late summer and autumn, however, a number of sheep in the

fields supplied with licks of both Moutere Hills soil and limonite went off in condition and appeared to be very definitely affected with bush-sickness. It was noticed, however, that certain sheep did not appear to be taking the licks, and it was thought possible that this was the main reason for the non-success obtained in the experiment.

In the following year it was decided to ensure that the sheep received regularly the particular supplements being tested, and arrangements were made to drench the sheep twice a week. A new line of hoggets obtained from the Wakefield locality, where bush-sickness is unknown, was purchased, and on arrival at Glenhope they were drafted into groups as uniform in weight as possible.

It was decided to test under the drench treatment (1) limonite ore, (2) Nelson soil, and (3) iron ammonium citrate. A fourth group, without drench, served as a control.

The sheep grazed, as a flock, in rotation two typical fields, which in previous years had been associated with considerable mortality. The sheep had access to salt, the only difference in management of the various groups being the drench treatments.

The limonite was obtained from the Onekaka locality, Nelson, and was very finely ground in a ball-mill, so that the whole sample passed a sieve with 165 meshes to the inch.

In preparing the drench, 2 oz. of limonite powder were placed in a jar with 40 oz. of water. The contents of the jar were well stirred, and then 100 c.c. of the suspension were rapidly poured into the drench bottle and used immediately for each sheep in the limonite group. It is estimated that each sheep received 3–4 gm. of limonite[1] at each drenching.

The soil used for drenching was obtained from the Cawthron Institute grounds, Nelson. It is a light loam of alluvial origin, and was selected originally on account of its high content (6 per cent. Fe_2O_3) of iron soluble in N/10 oxalic acid. The soil after grinding and sieving was used in the following manner. One pound of soil was placed in a jar with 40 oz. of water, and the contents of the jar were stirred until a muddy suspension was obtained. Of this suspension 100 c.c. were poured quickly into the drench bottle and given to each sheep in the soil group. It is estimated that each sheep received 7–9 gm. of the silt and clay fractions of the soil, and that the soil supplement thus administered contained 0·75–1 gm. iron as Fe_2O_3 soluble in N/10 oxalic acid.

The sample of iron ammonium citrate used for drenching was chemically pure. A 10 per cent. solution was made up and 30 c.c. of the solution was used, after dilution[2] to 100 c.c. with water, for each sheep in the iron-ammonium-citrate group. Each dose of iron-ammonium-citrate drench contained 0·75 gm. Fe_2O_3 equivalent.

The drench experiments were commenced early in October 1932, and were continued with but slight modification until the middle of April 1933, when certain sheep affected with bush-sickness were drafted out

[1] Later in the season the dose was reduced to one-third of this amount.

[2] Certain irregularities in live-weights of the sheep in this group are considered to be connected with the use in the early part of the season of this drench in too concentrated a form.

from the control and limonite groups. The sheep were weighed at fortnightly intervals and were kept under close observation throughout the whole period of the experiment. The weights of the individual sheep in the different groups are shown for the two periods October 12–April 16, and April 16–June 18 in Tables 1 to 4 (see Appendix). The average weights for each of the four groups at different dates during the experiment are plotted in Fig. 1.

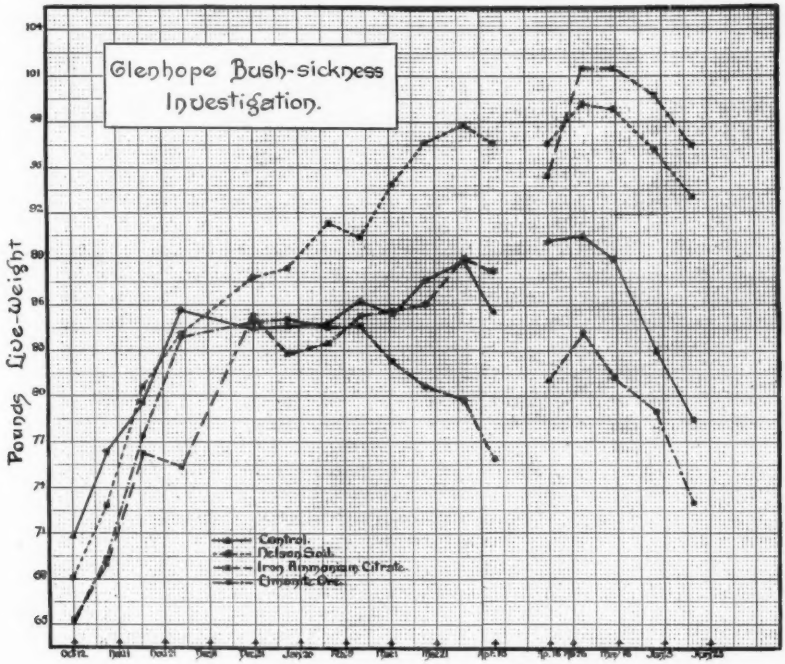

FIG. 1 Effects of Drench Treatments on Average Live-weights of different groups of Sheep

First period October 1–April 16; second period (after elimination of doubtful and badly affected sheep) April 16–June 18.

The live-weight averages show that the sheep in the different groups made rapid gains until the end of December. From this date the sheep in the control and limonite groups either remained stationary or went back slowly in condition. The iron-ammonium-citrate group contained only four sheep and the average weight was affected very materially by the poor progress made by one sheep. The remaining three did very well and on April 16 were almost equal in weight to the sheep in the Nelson-soil group. It must be remarked that during the first half of the trial striking variations in weight occurred in the sheep receiving the iron-ammonium-citrate drench, but when this drench was made more

dilute by the addition of water before administration, these irregularities did not occur. It is assumed, therefore, that the irregularities noted in the early part of the season for the sheep drenched with iron ammonium citrate were caused by the use of a too concentrated solution of this chemical.

The sheep with the Nelson-soil drench showed a consistent increase in weight throughout the whole season until April 16. Every sheep in the group was in excellent condition on this date and many could have been sold as fat sheep. They did not show the slightest symptom of bush-sickness, and in this respect contrasted strikingly with the sheep in the control and limonite groups, which showed definite signs of sickness early in February. The affected sheep slowly dropped in condition and by the middle of April nearly every sheep in these two groups was affected to some extent with bush-sickness. In certain cases the symptoms of ailment were acute.

On April 16 three sheep, in each case badly affected with bush-sickness, from both the control and limonite groups, and one sheep from the iron-ammonium-citrate group were drafted out. The remaining sheep in the original groups continued to receive their respective drench treatments throughout the autumn and the winter. The average live-weights for the sheep left in the different groups after April 16 show that those in the control and limonite groups continued to decline rapidly in condition. The sheep in the Nelson-soil and iron-ammonium-citrate groups, on the other hand, did relatively well and showed only a small decline in condition characteristic of winter grazing. The sheep in these two groups remained healthy and no symptom of bush-sickness has appeared.

Discussion

The most outstanding feature of the drench experiments conducted at Glenhope is the great success which has attended the use of Nelson soil, supplied as a supplement twice a week to the sheep-grazing pasture definitely associated with bush-sickness. The results of this experiment show the great importance of soil in the maintenance of stock health. The quantity of Nelson soil given as a supplement to the sheep at Glenhope is not greater than that which on many soils is likely to be ingested by stock during the grazing of pasture. If Nelson soil can effect such marked improvement in the health of stock-grazing pastures associated with bush-sickness, it is reasonable to expect that many other New Zealand soils will prove equally valuable, and that soils are just as important as the pasture growing thereon in supplying certain essential constituents required by stock.

The value of soil as a supplement in the rearing of pigs has long been recognized, and its importance in the control of nutritional anaemia has been confirmed by the recent experiments of Vald. Adsersen of the State Veterinary Laboratory, Copenhagen. Adsersen states that when pigs are kept indoors the haemoglobin-content of the blood may fall in the first three weeks to within one-third of the content at birth. A supply of fresh soil obtained from arable land proved to be the most effective

method in controlling nutritional anaemia, which causes considerable mortality in little pigs.

The exact role of soil in overcoming nutritional anaemia in pigs is not known, but Adsersen's report suggests that its value is greatly dependent on an adequate supply of iron compounds in the soil, for highly beneficial results were obtained by him from the use of ferrous sulphate for pigs kept indoors. The Nelson soil used in the Glenhope experiments was originally selected because of its comparatively high content (6 per cent. Fe_2O_3) of iron soluble in N/10 oxalic acid.

In view of the highly beneficial results reported by Aston [6] on the use of Whangarei limonite for stock on 'bush-sick' country in the North Island of New Zealand, by Orr [7] for 'Nakuruitis' in East Africa, where a lick of red oxide of iron and salt effected a control of the ailment, by Orr [8], and Greig and Dryerre [9] for 'pining' in Scotland, where ferric oxide and salt gave great improvement in the health of stock, and by Neal and Becker [10] for 'salt-sick' in Florida, where a lick of red oxide of iron, salt and a small proportion of copper sulphate cured animals affected with the ailment, the provision of an adequate and suitable supply of iron-containing compounds seems to be essential in the cure of nutritional anaemia of the bush-sickness type. Nelson soil, by virtue of its comparatively high content of easily soluble iron, undoubtedly falls within the category of compounds containing adequate amounts of iron, and if bush-sickness is actually due solely to deficiency in the iron supply of stock, it is not surprising that regular supplements of Nelson soil should prove as effective as the Whangarei limonite used by Aston in the North Island.

The failure of the Onekaka[1] limonite in the Glenhope experiments suggests, however, that at Glenhope, at least, the supply solely of iron-containing compounds is not sufficient for the prevention of ailment.[2] No suggestion can be offered, at the present time, concerning the value of other elements—possibly minor constituents—in overcoming bush-sickness at Glenhope, but it must be emphasized that our knowledge of the exact role of such elements as iron, copper, and manganese in the formation of haemoglobin is incomplete, and the presence of very small quantities of certain elements may have a profound effect on the proper functioning of the animal system.

Summary

(1) Sheep depastured on typical bush-sick country at Glenhope have been drenched twice a week with (*a*) Onekaka limonite, (*b*) Nelson soil, (*c*) iron ammonium citrate. A further group without drench treatment, but grazing the same pastures, served as a control.

(2) Sheep drenched with a small quantity of Nelson soil, containing 6 per cent. Fe_2O_3 soluble in N/10 oxalic acid, gained rapidly and

[1] Analyses by Miss E. B. Kidson, reported elsewhere, show that the sample of limonite used at Glenhope contained over 22 per cent. Fe_2O_3 soluble in N/10 oxalic acid, and had a total content of iron equivalent to 71·6 per cent. Fe_2O_3. For use as a lick, the limonite was ground to pass completely a sieve with 165 meshes to the inch.

[2] Confirmation of the above experiment with Onekaka limonite has been obtained with sheep in the Sherry Valley, Nelson, where the animals did not respond satisfactorily whether given the limonite as a lick or as a drench.

continuously in weight until the onset of winter. They remained perfectly free from bush-sickness and could have been sold as fat sheep in the autumn.

Sheep drenched with Onekaka limonite showed no improvement over the control sheep (without drench) and, as in the control group, a number became badly affected with bush-sickness. With one exception, the sheep drenched with iron ammonium citrate did well and remained free from bush-sickness, although great variation in the weights of individual sheep occurred during the period of the experiment.

(3) The failure of Onekaka limonite to overcome bush-sickness at Glenhope suggests that an adequate supply of iron compounds is insufficient in itself to prevent the appearance of ailment at Glenhope, and that some other factor operates detrimentally to the normal functioning of the animal system.

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The authors gratefully acknowledge the valuable help and painstaking care of Mr. Newton McConochie in the conduct of the drench experiments at Glenhope. They are also indebted to Miss E. B. Kidson of the Cawthron Institute for iron estimations in samples of Nelson soil and Onekaka limonite. The cost of the investigations has been defrayed partly from grants made by the Empire Marketing Board and the New Zealand Department of Scientific and Industrial Research, and this financial help is greatly appreciated.

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APPENDIX

GLENHOPE DRENCH EXPERIMENTS

TABLE 1. *Control Group—Season 1932–3*

Sheep weights (pounds)

Tag no.	*Oct. 12*	*Oct. 27*	*Nov. 12*	*Nov. 29*	*Dec. 31**	*Jan. 15*	*Feb. 2*	*Feb. 16*	*Mar. 2*	*Mar. 17*	*Apr. 3*	*Apr. 16*	*Apr. 16*	*May 1*	*May 15*	*June 2*	*June 18*
20	78½	85	86	94	98½	100	101	100	103	107	110	106¾	..	..	..	..	..
21	66½	69	73	78½	78½	77	79	78	79	80	82	82¾	82½	82½	80¼	75½	72½
22	79½	87	92	103½	97½	97	95	101	101	105	103	88¼	88½	97½	98½	92½	87½
23	59½	70	76	72½	61½	60	64	64	59	58	57	52¾	..	..	..	..	..
24	77½	83	84	92½	94½	94	92½	94	94	97	99	99¾	99¾	94½	90½	81½	77½
25	68½	71	70	77	76½	81	78	80	76	77	80	78¾	..	..	..	..	..
26	65½	70	76	82	84½	83	84	87	86	89	91	89¼	89¾	87½	86½	82½	76½
Aver.	70·8	76·4	79·6	85·7	84·5	84·6	84·8	86·3	85·4	87·6	88·8	85·6	90·2	90·5	89·0	83·0	78·5

* Sheep shorn prior to weighing.

TABLE 2. *Limonite Group—Season 1932–3*

Sheep weights (pounds)

Tag no.	*Oct. 12*	*Oct. 27*	*Nov. 12*	*Nov. 29*	*Dec. 31**	*Jan. 15*	*Feb. 2*	*Feb. 16*	*Mar. 2*	*Mar. 17*	*Apr. 3*	*Apr. 16*	*Apr. 16*	*May 1*	*May 15*	*June 2*	*June 18*
1	64½	69	81	85½	86½	89	88	88	84	82	84	81¾	81¾	85½	83½	79½	73½
2	65½	71	76	83½	84½	86	82	82	81	79	77	72¼	72¼	78½	76½	75½	70½
3	60½	64	70	78½	79½	79	76	76	71	61	58	50¾	..	..	..	..	..
4	65½	74	90	97½	96½	97½	100	98	94	97	106	103¾	..	..	..	..	..
5	70½	73	80	88½	84½	87	83	78	74	68	58	52¾	..	..	..	..	..
6	65½	66	68	73½	76½	72	76	80	83	87	88	81¾	81¾	87½	84½	82½	70½
7	63½	68	77	80½	86½	85	89	90	89	90	87	87¾	87¾	85½	80½	78½	77½
8	68½	74	80	87½	(died; not bush-sick)												
Aver.	65·1	69·3	77·4	83·9	84·9	85·1	84·6	84·6	82·3	80·6	79·7	75·9	81·0	84·2	81·25	79·0	73·0

* Sheep shorn prior to weighing.

GLENHOPE DRENCH EXPERIMENTS

TABLE 3. *Nelson-soil Group—Season 1932–3*

Sheep weights (pounds)

Tag no.	Oct. 12	Oct. 27	Nov. 12	Nov. 29	Dec. 31*	Jan. 15	Feb. 2	Feb. 16	Mar. 2	Mar. 17	Apr. 3	Apr. 16	Apr. 16	May 1	May 15	June 2	June 18
9	71½	74	81	88½	89½	89	92	94	97	100	102	102¾	102¾	101½	101½	99½	94½
10	74½	77	87	84½	94½	94	97	99	101	102	109	107¾	107¾	106½	108½	106½	103½
11	59½	67	73	79½	77½	79	83	78	80	87	88	85¾	85¾	92½	90½	88½	86½
12	61½	68	79	90½	92½	92	94	93	96	96	101	101¾	101¾	97½	101½	98½	95½
13	71½	76	77	85½	86½	88	91	87	93	97	99	96¾	96¾	101½	99½	98½	92½
14	61½	67	79	74½	77½	79½	81	81	87	90	91	92¾	92¾	91½	88½	85½	84½
15	76½	81	88	85½	96½	97½	101	101	103	105	95†	88¾	88¾	103½	101½	96½	94½
Aver.	68·1	72·9	80·6	84·1	87·8	88·4	91·3	90·4	93·9	96·7	97·8	96·6	96·6	99·2	98·8	96·2	93·1

* Sheep shorn prior to weighing.
† This sheep was badly staked; it was treated and made a quick recovery.

TABLE 4. *Iron-ammonium-citrate Group—Season 1932–3*

Sheep weights (pounds)

Tag no.	Oct. 12	Oct. 27	Nov. 12	Nov. 29	Dec. 31*	Jan. 15	Feb. 2	Feb. 16	Mar. 2	Mar. 17	Apr. 3	Apr. 16	Apr. 16	May 1	May 15	June 2	June 18
16	78½	82	87	75½	101½	98	85	76	89	98	109	110¾	110¾	109½	102½	100½	94½
17	58½	66	77	80½	88½	84	79	72	85	90	97	95¾	95¾	112½	109½	106½	100½
18	62½	65	73	76½	76½	75	81	89	79	75	72	66¾†	..	..	..	..	..
19	61½	63	68	68½	74½	74	89	104	89	81	78	79¾	79¾	82½	92½	92½	94½
Aver.	65·3	69·0	76·3	75·3	85·3	82·8	83·5	85·3	85·5	86·0	89·0	88·3	95·4	101·5	101·5	99·8	96·5

* Sheep shorn prior to weighing.
† This sheep is ailing, but there is some doubt as to the nature of the ailment.

Sheep receiving regular drench of Nelson soil. Seven months from the commencement of the experiment

Bush-sick sheep from limonite and control groups. Seven months from the commencement of the experiment

WOOL-GROWTH IN SHEEP AS AFFECTED BY THE CARBOHYDRATE-CONTENT OF THE DIET

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Introduction.—It is known that the quantity and quality of wool is affected by the nutritional plane of the sheep. Thus Hardy and Tennyson [1] showed that both the growth and coarseness of wool were greatest in summer or autumn and least in midwinter, and that there appeared to be a close relationship between the thriftiness of a sheep and the quality and quantity of wool it produces. Wilson [2] and Weber [3], as a result of feeding experiments, showed that the plane of nutrition had a marked influence on wool-production. Weber found that sheep full fed on ground corn and alfalfa meal produced more, longer, and coarser wool than those fed on alfalfa meal in such amounts as to cause a slight loss in body-weight.

Owing to the protein nature of wool, nutritional research has been mainly centred on the protein or constituent amino-acids of the sheep's diet. Thus Marston and Brailsford Robertson [4] suggested that dietary cystine was the probable limiting factor in wool-production. In the 'Meteor Downs' experiment, Marston [5] found that bloodmeal (protein of high cystine-content), fed *ad lib.* to Merino sheep under natural conditions, resulted in a 30 per cent. increase in average fleece-weight. It was found that the intake of bloodmeal varied with the prevailing fodder conditions, more being taken in the winter months. On the other hand, Fraser and Roberts [6] were unable to influence wool-production by a 50 per cent. variation in the intake of digestible protein.

Recently Duerden, Bosman, and Botha [7] have shown that a deficiency of phosphorus in a sheep's diet results in a lighter fleece, of shorter length and finer quality, as compared with sheep fed on a sufficiency of phosphorus. The food-consumption of the sheep on the phosphorus-deficient diet was, however, very considerably reduced [8].

The energy value of the diet is known to be of primary importance in body-growth, but the influence of this factor on wool-production has been insufficiently studied. Yet under range conditions of sheep-farming, whether during the cold winters of temperate countries or the periodical droughts of warmer regions, it is likely to be one of fundamental practical importance. For the investigation of this question, a joint experiment between the Rowett Research Institute and the Wool Industries Research Association was planned. One group of ten sheep was fed a maintenance diet adequate in protein, minerals, and vitamins. A second group of ten sheep received the same diet supplemented with maize starch. Any group differences in the quantity or quality of wool grown could therefore be directly attributed to the starch supplement or to its absence.

Methods.—Twenty Cheviot wether hoggs were divided into two groups of ten, the groups being comparable in age, weight, and quality. The sheep were fed indoors, with moss litter as bedding, for a period of 154 days (December 12, 1932 to March 25, 1933). The animals were weighed individually at 7-day intervals. The basal ration was adjusted from time to time to maintain the initial body-weight of the basal group. Identical alterations were made in the rations of the two groups. The details of the dietary plan are shown below:

Group I	*Group II*
Basal ration	Basal ration
Linseed-cake meal . . ¼ lb. per sheep daily	*plus*
Turnips . . . 3 lb. per sheep daily	200–500 gm. maize starch per sheep daily
Oat straw . . ½ lb. per sheep daily	

Lime 2·2 per cent. of linseed meal fed
C.L.O. 2½ c.cm. per sheep daily
Water and salt-licks *ad lib.*

The purity of the starch was tested by determining its nitrogen-content. This was found to be 0·058 per cent., showing that the starch was sufficiently pure for the purposes of the experiment.

At the beginning of the experiment a triangular area was mapped out by iridectomy knife and Indian ink on the skin over the left shoulder of each sheep. The wool within this area was closely clipped with scissors and the sample removed for detailed examination. The fleeces were then shorn with a shearing machine and individually weighed. At the end of the experiment samples were again clipped from the tattooed areas, and the complete fleeces were shorn and weighed. The second samples and second fleece-weights were therefore those of the wool grown during the experiment on diets of known quantity and composition.

Results

Food-consumption.—The total food consumed during the experiment is shown below.

Total food-consumption during 154 days

Group I (10 sheep)		*Group II* (10 sheep)
Linseed cake . . .	749 lb.	As Group I, plus 1,315 lb. maize starch.
Turnips . . .	6,860 ,,	
Oat straw . . .	770 ,,	

Body-weight.—The effect of the added starch in increasing body-weight is shown in Table 1. The percentage increase in body-weight of Group II was ten times that of Group I.

Wool-analysis

In examining the effects of nutritional influences upon fleece-growth, both the amount of fibre-material produced and the form which it assumes have to be considered. From the sheep-owner's point of view, the financial return is a function of these factors and also of the proportion of non-wool materials in the shorn fleece. In the discussion of

TABLE 1. *Body-weight in lb.*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	64·5	62·5	−3·1	2	66·8	77·0	+15·3
3	57·3	57·5	+0·3	4	69·0	93·5	+35·5
5	64·6	67·5	+4·5	6	63·3	101·5	+60·3
7	69·6	83·5	+20·0	8	74·0	115·0	+55·4
9	65·8	69·5	+5·6	10	74·0	111·0	+50·0
11	53·6	57·0	+6·3	12	58·6	93·5	+59·5
13	69·0	64·0	−7·3	14	51·6	93·0	+80·2
15	53·0	55·5	+4·7	16	57·0	98·5	+72·8
17	77·0	84·0	+9·0	18	53·0	97·0	+83·0
20	57·5	68·0	+18·3	19	65·0	104·0	+60·0
Mean	63·19	66·90	+5·83		63·23	98·4	+57·2
S.E.	±2·45	±3·20	±2·69		±2·54	±3·35	±6·45

Differences: pre-experimental, 0·04; experimental, 31·5±4·63; percentage change, 51·4±6·99.

experimental results, also, it is necessary to realize that the fibres are not the only products involved in fleece-growth; parts of the 'grease' fraction constitute a like drain upon the activity of the follicles. In so far as these are ancillary to elaboration of fibre, they may not be neglected from any estimate of the requirements of the follicles in respect of any particular nutritional element; so that the estimation of the demands for follicle-growth, derived from analyses of fibre-constituents, may well be regarded as yielding a minimal figure.

For the present purpose, however, these other products [9, 10] will not be considered beyond their general inclusion in the greasy fleece.

(*a*) *Fleece-weights.*—The sheep were clipped on December 15, 1932, and again at the end of the experimental period, on May 25, 1933, the gross fleece-weights being recorded. From December 6, 1932, until the start of group-feeding (December 22) both groups were kept on the basal ration, hence the fleeces of Group I represent 161 days' growth with the animals on the basal ration, and those of Group II represent 7 days on the basal ration and 154 days with the starch supplement. Any difference in fleece-growth due to this relatively small discrepancy and also to (*a*) the possible effects of portions of the fibres remaining within the follicles, below skin or clipping level, and (*b*) any 'carry over' growth influence, may be regarded as negligible compared with the amounts grown over such an extended period of experiment.

The pre-experimental fleeces include the changes of the natal coat and the subsequent early stages of maturation; moreover, the length of their growing periods is not precisely known. They are therefore not strictly to be compared with the experimental fleeces so far as fibre-characters are concerned, but the procedure of expressing the differences as percentage changes serves to give measures of the effects of the experimental feeding upon growth.

Throughout the discussion the difference between the experimental growth and that grown previously is expressed as a percentage change on the latter for each individual. In both groups alterations in production occurred in all animals, and the directions and orders of the changes are

considered. Also, and for the same reason, the mean values of fibre-length, fineness, &c., for each individual are not weighted in considering the differences between the groups.

The gross fleece-weights of the animals are given in Table 2. Before being subjected to the experimental rations the mean fleece-weights of the groups were not significantly different, but the difference in the amount produced during the course of the experiment was significant.

TABLE 2. *Fleece-weights (in gm.)*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	1580	494	−68·7	2	1730	725	−58·1
3	1580	304	−80·8	4	1910	540	−71·7
5	1500	305	−79·7	6	1580	1105	−30·1
7	1510	605	−53·3	8	1500	1170	−22·0
9	1280	524	−59·1	10	1350	928	−31·3
11	1350	534	−60·4	12	1780	872	−51·0
13	1470	223	−84·8	14	1380	858	−37·8
15	1230	302	−75·5	16	1660	965	−41·9
17	1750	648	−63·0	18	1330	835	−37·2
20	1330	662	−50·2	19	1280	1065	−16·8
Mean	1458	460·1	−67·5		1550	906·3	−39·8
S.E.	±50·70	±51·36	±3·84		±68·37	±59·04	±5·28

Differences of means: Fleece-weights: pre-experimental, 92±85·12; experimental, 446·2±78·26; percentage change, 27·7±6·53.

The group receiving the starch supplement, as judged by the fleece-weights, produced almost twice as much as those on the basal ration. The fleeces of Group II, however, contained much adventitious starch, giving them a markedly different appearance and handle, so much so that a trade estimation of yield of clean wool could not be made. The effect on the amounts of wool grown can be judged from the samples taken from the tattooed areas; a rough estimate can be made on the broad assumption that the clean yield of each fleece as a whole was the same as that of the defined sample.

The amounts of wool thus estimated are given in Table 3, which indicates that the wide difference in growth upon the two rations is also expressed when the fibre-product alone is considered.

In general appearance the fleeces of the animals in Group II exhibited longer, denser, and thicker staples than those of Group I.

(*b*) *Area samples.*—The samples were taken from the defined areas on December 6, 1932, and again on May 24, 1933; the wool-growths represented therefore are those of 169 days on the basal ration for Group I, and 15 days on basal ration, followed by 153 days on the starch supplement for Group II. The samples were exposed for two days in the laboratory atmosphere and weighed in the 'raw' state before being subjected to the standard procedure of analysis [11], viz. washing with three changes of warm benzene, air-drying, and washing with three changes of distilled water. After final drying the clean-dry weights were determined by weighing against a standard sample of known clean-dry weight. To compare roughly the amounts of wool grown, the 'yield' of wool was calculated by expressing the clean-dry weights as percentages of the

TABLE 3. *Sample Yield and Estimated Weight of Clean Fleece*

Group I					*Group II*				
	Pre-exptl.		*Exptl.*			*Pre-exptl.*		*Exptl.*	
Animal	*Sample yield** %	*Estmd. clean fleece-weight*	*Sample yield** %	*Estmd. clean fleece-weight*	*Animal*	*Sample yield** %	*Estmd. clean fleece-weight*	*Sample yield** %	*Estmd. clean fleece-weight*
1	79·0	1248	74·5	368	2	78·3	1355	56·7	411
3	79·2	1251	66·9	203	4	77·3	1476	65·8	355
5	80·1	1202	68·3	208	6	81·0	1280	47·9	529
7	80·7	1219	75·9	459	8	7·3	1115	52·8	618
9	79·3	1015	70·2	368	10	76·4	1031	57·4	533
11	79·2	1069	72·2	386	12	80·5	1433	62·9	548
13	79·4	1167	66·5	148	14	78·6	1085	56·4	484
15	78·6	967	62·4	188	16	82·0	1361	67·9	655
17	79·8	1397	69·6	451	18	79·2	1053	66·7	557
20	76·6	1019	73·3	485	19	75·0	960	55·3	589
Mean	79·2	1155·4	70·0	326·4		78·3	1214·9	59·0	527·9

* Clean-dry wool as percentage of raw (greasy) wool.

weights of the raw samples. (It should be noted that the yields before and after experiment are not strictly comparable owing to possible differences in atmospheric humidity obtaining when the samples were weighed.) These are the values given in Table 3. A marked difference in yield between the groups occurred at the end of the period, presumably much greater than would be expected from starch-contamination alone. It is therefore concluded that a greater elaboration of non-wool products had taken place in Group II, as well as a greater production of fibre.

The attempt was made to secure areas of similar size when they were first defined, although this was only possible within wide practical limits. It is unnecessary to give details of the raw sample-weights; in general they followed changes similar to those of the raw fleece-weights, shown in Table 2. The mean raw sample-weights were, before experiment, Group I, 5·72 gm.; Group II, 6·51 gm., with standard errors $\pm$0·28 and $\pm$0·60 respectively; after experimental feeding, Group I, 2·04 gm. with error $\pm$0·12, and Group II, 4·28$\pm$0·47. Between the two groups there occurred a difference in the mean percentage changes in raw weight of 30·82, with standard error $\pm$6·70 (cf. Table 2).

The clean-dry weights of the samples are given in Table 4. Whereas prior to experimental feeding there was an insignificant difference of 0·6 gm. between the mean dry weights, after the period of feeding the difference was 1·1 gm., with standard error $\pm$0·33; and while the production of fibre-substance in Group I, on the basal ration, changed 67·4 per cent. ($\pm$3·27), the mean amount grown on the defined areas of the sheep that were fed on the basal ration and starch, changed by 49·8 per cent. ($\pm$4·30). The significance of this difference in production confirms the above conclusion to the effect that the starch supplement definitely favoured wool-growth.

(*c*) *Fibre-length.*—In the determination of mean fibre-length, the method of zoning and measuring elaborated by Roberts [11] was used. The original samples were each divided into eight zones, and the proportions of fibres measured from the final sub-samples were 1 in 3 or 1

TABLE 4. *Clean-dry Weights of Samples (in gm.)*

Group I				*Group II*			
Animal	*Pre-Exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-Exptl.*	*Exptl.*	*Per cent. change*
1	5·33	1·84	65·5	2	5·65	1·69	70·1
3	4·46	0·93	79·2	4	4·86	1·46	70·0
5	5·15	1·57	69·5	6	4·82	2·19	54·6
7	4·86	1·83	62·3	8	3·08	1·79	41·9
9	4·10	1·25	69·5	10	3·13	1·48	52·7
11	3·50	1·53	56·3	12	7·82	3·27	58·2
13	5·00	1·03	79·4	14	6·15	3·78	38·5
15	5·29	1·23	76·7	16	7·21	3·98	44·8
17	4·31	1·35	68·7	18	5·03	3·38	32·8
20	3·34	1·78	46·7	19	3·51	2·31	34·2
Mean	4·53	1·43	67·4		5·13	2·53	49·8
S.E.	±0·23	±0·10	±3·27		±0·52	±0·31	±4·30

Differences: pre-experimental, 0·6±0·57; experimental, 1·1±0·33; percentage changes, 17·6±5·40.

in 4, in the pre-experimental samples, and 1 in 8 or 1 in 10 in the samples taken at the end of the experimental period. The fibres were measured to the nearest half-centimetre.

In zoning and in counting out the fibres to be measured, great care was exercised to reduce as much as possible the chance of breaking fibres. In some samples, especially among those of Group I, taken after the feeding period, a considerable number of very short fibres (of less than half the mean fibre-length) were found. These caused the distribution of fibre-length in the particular samples to exhibit marked skewness, but their contribution to the total lengths of the fibre was small. (The greatest proportion was found in animal number 4, Group II, after experiment, where short fibres, of 2 cm. or less, formed 34·9 per cent. of the fibres measured; their contribution to the total length was, however, only 6 per cent.) In measuring, the short fibres were treated as separate groups, and they are not included in the figures for mean fibre-length, shown in Table 5. Since the total length enters into the determination of fineness, the short fibres are involved in the calculation of the results shown in the succeeding sections.

TABLE 5. *Mean Fibre-lengths (in cm.) excluding Short Fibres*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	9·5	5·6	−41·6	2	9·9	5·5	−44·4
3	9·2	4·2	54·4	4	10·3	6·7	35·0
5	10·4	6·3	39·4	6	9·5	6·5	31·6
7	10·8	6·4	40·8	8	9·1	6·4	29·7
9	9·3	5·9	36·6	10	9·7	6·7	30·9
11	8·9	5·9	26·8	12	11·7	7·2	38·5
13	8·2	5·1	37·8	14	9·4	7·3	22·3
15	8·1	5·2	35·8	16	10·1	7·4	26·7
17	9·5	5·7	40·0	18	8·7	7·2	17·2
20	8·3	6·0	28·4	19	7·1	5·6	21·1
Mean	9·22	5·62	38·1		9·55	6·65	29·7
S.E.	±0·28	±0·21	±2·40		±0·37	±0·21	±2·62

Differences of means: pre-experimental, 0·33±0·47; experimental, 1·02±0·30; percentage changes, 8·4±3·56.

In so far as fibre-lengths affect the appearance of staple-length in such wools, these figures illustrate one aspect of the difference between the groups. The change in production, considered from the standpoint of fibre-length alone, was marked in the basal-ration group, and the feeding of the starch supplement conferred a small but significant advantage in respect of growth in fibre-length.

If the short fibres are included, this distinction between the groups tends to be diminished and the effect of the different nutritional levels is reduced. The position in respect of mean fibre-lengths with short fibres included is summarized in Table 6.

TABLE 6. *Mean Fibre-lengths, including Short Fibres*

	Group I	*S.E.*	*Group II*	*S.E.*
Pre-experimental . .	8·98	±0·29	9·29	±0·40
Experimental . . .	5·30	±0·30	6·07	±0·26
Per cent. change, mean .	41·0	±3·01	33·8	±3·42

This points to the conclusion that the difference in production on the sample areas was expressed more in other ways than in mere length of fibre grown, so that the other factors of average fibre-fineness, and, possibly, the number of fibres produced (i.e. number of active follicles), have to be taken into consideration.

(*d*) *Average fineness.*—After counting and measuring the fibres, the sub-samples were washed in benzene and their clean-dry weights were determined. From the calculated total lengths of fibre and these weights, the values for fineness expressed as length (in cm.) per unit weight (mgm.) were derived.

Even under ordinary conditions, some change in fineness might be anticipated in all the animals, as the growth-periods cover two different stages in the maturation of the lamb's coat. The two groups at the outset were well balanced as regards fineness, and it will be seen that the different metabolic levels produced markedly dissimilar effects. In all animals, except No. 19 (Group II), the wool was distinctly finer at the end of the feeding period, and there is some general similarity between the changes in individual fineness and those in individual body-weight (cf. Tables 1 and 7).

These figures not only show responses of different magnitudes in the two groups, there being less alteration of fineness in the starch-supplement group, but also indicate a differential response as between length-growth and fineness. In Group I the reduction of growth conditions to the basal ration led to a difference in fibre-length production of 41 per cent. and a difference in fineness of 53 per cent.; whilst in Group II the effect of the starch supplement was to limit the orders of the reductions to 33·8 per cent. in length and 21·4 per cent. in fineness. That is, the administration of the starch supplement gave a level of fibre-production which was nearer to that under pre-experimental conditions, by affecting both fibre-length and fineness; but the proximity to the pre-experimental growth in Group II (as compared with Group I) was

TABLE 7. *Average Fineness*

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	112	167·3	+49·4	2	89	144	+61·8
3	132	206	56·1	4	114	140	22·8
5	104	159	52·9	6	94	120	27·7
7	116	163·5	41·0	8	105	112	6·7
9	118·5	191	61·2	10	98	117	19·4
11	88	124	40·9	12	113	144	27·4
13	113	175	54·9	14	119	144	21·0
15	143	281	96·5	16	125·5	146	16·3
17	97	159	63·9	18	114	127	11·4
20	117	132·6	13·3	19	162	161	−0·6
Mean	114·1	175·8	53·0		113·4	135·5	21·4
S.E.	±5·02	±13·97	±6·64		±6·51	±4·95	±5·32

Differences of means: pre-experimental, 0·7; experimental, 40·3±14·82; percentage changes, 31·6±8·51.

achieved more by encouraging the coarser (less fine) growth than by sustaining the fibre-length growth. In other words, the fibres tended to respond to the starch supplement more in the direction of greater thickness ('diameter') than in greater length-growth. (*Note*: the values for fineness as expressed in cm./mgm. are inversely proportional to the squares of fibre 'diameters'.) So far as the average fibre-growth is concerned, the situations are epitomized in the average fibre-volumes produced under the two nutritional levels.

(*e*) *Average fibre-volume.*—The factors of mean fibre-length and average fineness can be combined to give measures of the volume of fibre-production. On the assumption that the density of the fibre-substance remains constant in wools of the same type, average fibre-volume is proportional to mean length upon average fineness. These values are shown in Table 8.

TABLE 8. *Average Fibre-volume*

	Group I	*S.E.*	*Group II*	*S.E.*
Pre-experimental . .	0·080	±0·0048	0·085	±0·0059
Experimental . . .	0·032	±0·0034	0·045	±0·0028
Per cent. change, mean .	60·2	±3·53	44·3	±4·46

Since in Group I the change in mean length was of the order of 41 per cent., the remainder of the average change in fibre-volume, i.e. 19 per cent., must be attributed to change in 'diameter'; similarly in Group II, with length accounting for 34 per cent., the 'diameter' may be considered as contributing 10 per cent. to the average change in fibre-volume. Thus in the *decrease* of fibre-growth due to the basal ration, the growth in respect of length contributed approximately twice as much as the change in thickness or 'diameter', whilst in the *decrease* on the pre-experimental condition of the starch-supplement group, the change in length was responsible for about three times as much as the change in 'diameter'.

The changes in the total production of clean wool on the defined areas

(see Table 4) were of the order of 67 per cent. and 50 per cent. in Groups I and II, respectively, so that in each case there appears a margin beyond that attributable to alterations in average fibre-volume. The practical difficulties in recording with accuracy any actual change in the extent of a defined skin area on the living animal preclude the possibility of estimating contributions from such a source. Also differences in the amount of medullation present in the fibres affect the accuracy of the estimates of average fineness and fibre-volume.

(*f*) *Estimated number of active follicles.*—The possibility of change in the number of follicles actively producing fibres on any area has been frequently neglected in studies of wool-growth, although such a phenomenon may conceivably occur according to age, season, or nutritional supply to the follicle, and has been demonstrated in the guinea-pig [12]. The observation that the starch-supplement group tended to exhibit denser and bulkier staples, which was confirmed when the samples of different wools from different areas were examined by an experienced wool buyer, emphasized the desirability of considering this factor. As with the other fleece characters, any difference between the two groups could reasonably be attributed to the effects of the ration.

The estimates of number of active follicles were made from the clean-dry weights of the sample and the zoned sub-sample, and the number of fibres included in the latter.

TABLE 9.

Estimated Number of Active Follicles (*00 omitted*)

Group I				*Group II*			
Animal	*Pre-exptl.*	*Exptl.*	*Per cent. change*	*Animal*	*Pre-exptl.*	*Exptl.*	*Per cent. change*
1	652	558	−14·4	2	524	467	−10·9
3	666	523	21·5	4	551	444	19·4
5	517	422	18·4	6	492	465	5·5
7	534	473	11·4	8	379	325	14·3
9	546	414	24·2	10	335	265	21·0
11	358	323	9·8	12	756	688	9·0
13	692	473·5	31·6	14	784	785	+0·1
15	955	779	18·4	16	908	851	−6·3
17	453	384·5	15·1	18	688	648	5·8
20	484	397	18·0	19	822	723	12·0
Mean	586	475	18·3		624	566	10·4
S.E.	±52	±40	±2·02		±62	±63	±2·07

Differences of means: pre-experimental, 38±81; experimental, 91±75; percentage changes, 7·9±2·89.

Whatever may be the causes of the changes in the number of active follicles, as shown by these estimates, the numbers are apparently lower in the basal-ration group than in that receiving the starch supplement, although the differences are not significant. Regarded from the aspect of percentage changes in individuals, the alterations in Group I are greater than in Group II, suggesting that this factor may have contributed to the margin in fleece-production over and above that assessable to the output of fibre-substance (volume) by the active follicles.

Conclusions

The advantage in respect of gross fleece-weight conferred by adding the starch supplement to the basal ration is shown from the study of the defined sample areas to be largely due to the greater activity of the follicles in the elaboration of fibre-material. When the difference in fibre-production is expressed in terms of the average fibre-volume, the starch-fed group showed a decrease on their performance prior to experiment of 44 per cent., as contrasted with a diminution of 60 per cent. in the basal-ration group. (This omits the distinction due to the different periods of time of pre-experimental and experimental growth.) The margin of difference between the order of such estimated change in fibre-volume and that of the amount of clean wool produced is possibly attributable to an alteration in the number of follicles which are actively producing fibres. In Group I, on the basal ration, 18 per cent. fewer follicles were estimated to be operative, whilst in Group II the estimated diminution was 10 per cent.; in the former, those which were producing were doing so at the rate of 0·032 volume-units during the experimental period; in the latter their average volume-production was 0·045 units.

The mean length of fibre, all fibres included, did not differ significantly in the two groups, but if the shorter fibres (which conceivably contribute little to the apparent staple-length) are neglected, the average growth on the sample areas of the starch-fed group was about 1 cm. longer than that on the areas of the basal-ration group. The difference in rate of production due to the starch supplement was manifested more as a difference in the fineness of the fibres, in the sense that the fibres were maintained at a fineness nearer to their pre-experimental value than were those grown in the basal-ration group, the respective differences being, in length, Group I 41 per cent. and Group II 34 per cent., and in fineness 53 per cent. and 21 per cent.

Discussion

The addition of starch to the maintenance ration of young Cheviot sheep produced a significant increase in both fleece-weight and body-weight. The increase of fleece-weight was largely due to a definite increase in fibre-thickness, a slight increase in fibre-length, and possibly also to an increase in the proportion of follicles actively elaborating fibres. Additional carbohydrate in the diet therefore led to the increased production of a substance predominantly protein in nature.

The depression of wool-production in the basal group might presumably be due to one of two causes:

(*a*) The protein in the diet might have been used mainly for supplying energy. The influence of starch in increasing wool-production would then be an illustration of the well-known protein-sparing action of carbohydrates.

(*b*) The activity of the wool follicles might have been depressed by the low energy-content of the basal diet. The addition of the starch would then have increased the metabolic activity of the follicles, leading to increased rate of elaboration of their characteristic product.

The theoretical question at issue is whether the depression of wool-production in the basal group was due to decreased activity of the wool-follicle, or to a deficiency of the substances required for the material expression of that activity. It is possible that both factors were involved.

The results of the experiment have an important practical application to pastoral conditions. Owing to the protein nature of wool, it has been widely assumed that reduced wool-production must be associated with deficiency of protein in the pasture. Yet under drought or other famine conditions where sheep are losing weight, it is evident that any protein supplement fed will be used in the first place as a source of energy. It is therefore obviously equally efficacious, and usually more economic, to feed the cheapest available carbohydrate supplement of high caloric value. Such a supplement, in the light of the experiment here recorded, may be expected not only to maintain normal body-weight, but normal wool-production as well.

Summary

(1) One group of ten growing sheep was fed on a maintenance ration. A second group of ten was fed on the same ration supplemented with maize starch.

(2) The starch produced a significant increase in both body-weight and gross fleece-weight.

(3) The increase in gross fleece-weight was reflected in the weight of clean wool.

(4) This increase was due to a definite increase in fibre-thickness, a slight increase in fibre-length, and possibly also to an increase in the proportion of follicles actively elaborating fibres.

(5) Theoretical interpretations and the practical applications of the experimental results are discussed.

Acknowledgements

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RECENT DEVELOPMENTS IN THE AGRICULTURE OF SUGAR-CANE IN QUEENSLAND

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(*Bureau of Sugar Experiment Stations*)

Introduction.—The Queensland Bureau of Sugar Experiment Stations was constituted in 1900 to 'conduct experiments in connexion with sugar-cane and sugar and the by-products thereof, to prevent the spread of disease in cane, and otherwise to promote the well-being of the sugar industry'. The Bureau is maintained by a levy assessed on all cane delivered for manufacture, together with a Government endowment approximately equal to the amount of the compulsory levy.

The first Director of Sugar Experiment Stations was Dr. Walter Maxwell, who accepted an invitation to take charge of the new organization while Director of the Hawaiian Station. The head-quarters of the Bureau was established at Bundaberg, where a chemical laboratory was provided. The field station was situated at Mackay, which was then a most important sugar area; it is situated in latitude 21° S., and although it enjoys a fairly high average rainfall (64 in.), the distribution is quite erratic, long periods of drought being frequent.

In 1909 Dr. Maxwell retired, the Bundaberg laboratory was closed, and the head-quarters of the Bureau was transferred to Brisbane. In 1913 a second experiment station was created at Bundaberg, on an area of red volcanic soil. The average annual rainfall at Bundaberg is 42 in., and moisture deficiency is a factor seriously limiting crop-growth. The latitude is 25° S., and damage to cane by frost is frequent.

In 1914 an entomological station was established in the Cairns district, where the 'cane-borer' (*Rhabdocnemis obscurus* Boisd.) and the 'white grub' (*Lepidoderma albohirtum* Waterh.) are serious pests; and in 1918 the third experiment station was created at South Johnstone. This station is situated in the centre of the humid tropical belt (latitude 17½° S., mean annual precipitation 130 in.). The soil is an alluvial clay loam of granitic origin.

Repeated attempts to raise cane seedlings at the Bundaberg and Mackay stations proved unavailing; but as it was found that the favourable environment of South Johnstone made for profuse arrowing, and cross-pollinations were possible, the raising of seedlings was instituted there in 1921.

Up to 1924 the Bureau had not been able to lend as much help to the industry in soil science, pathology, and mill technology as it had hoped to do, largely owing to the difficulty in securing trained officers. In that year three selected University graduates were sent abroad to study those important aspects of scientific agriculture, control of pests and diseases, and sugar-mill technology. On their return in 1928 the Bureau was reorganized, and each was placed in charge of the respective Divisions for which he had been trained, with the Director (the late H. T. Easterby) as administrative head. Well-equipped chemical and biological labora-

tories were provided at Brisbane, and the Bureau was then in a position greatly to extend all phases of the work on the agriculture of sugar-cane.

It is the purpose of this contribution to review briefly the advances which have been made since 1928, and to indicate the lines along which agricultural research work is proceeding.

Field Experimentation

Prior to this time, all field trials had been confined to the stations. Though many valuable data were obtained in this way, it was realized that the restricted range of soil types and other factors which could be studied at these centres constituted but a small sample of conditions throughout the entire sugar-belt, which extends as an interrupted coastal strip some 1,100 miles long (see Fig. 1).

A series of experimental areas located on private farms was therefore instituted. The trials were set out and supervised by the field staff of the Bureau, and all cultural operations outside the scope of the investigations were left to the discretion of the farmer. The results of the policy have been highly successful, and it is found that the returns from such trials undoubtedly carry greater conviction to farmers than those obtained at experiment stations.

It was a happy circumstance that the excellent researches of Fisher at Rothamsted had just provided the improved technique which was so highly desirable in work of this nature. For qualitative fertility trials the 5×5 Latin square was admirably adapted, five treatments being made, viz. control, N P, N K, P K, N P K. The plot-size was so adjusted that the produce from one plot could be transported to the mill on a small cane-truck of capacity 35–50 cwt., and the exact yields were obtained over the mill weigh-bridge. The range of area was from 1/10 to 1/25 acre. In special circumstances weighing in the field is necessary, for which purpose a tripod and a 200-lb. spring-balance are employed. The area of the plot is then reduced to 1/25–1/40 acre.

After a little experience the agriculturists were able to select suitable experimental areas free from serious soil irregularities; and by employing reasonable precautions the standard error of the mean of five plot-yields is of the order of 3 per cent. Errors of less than 2 per cent. are frequently recorded, even under irrigated conditions. The use of guard rows to eliminate border influences has so far been neglected. They introduce harvesting problems, and careful observation suggests that if due care is taken in the placement of the artificial manures, the border effect may be reduced to an insignificant minimum. All phosphates and potash are applied in the planting furrow with the cane sets, and top dressings of sulphate of ammonia are carefully placed on the outer plot rows, on the side removed from adjacent plots receiving no nitrogen. It is felt that any slight irregularities which may enter serve to introduce an element of conservatism in the final conclusions. Further, it is only where the influence of a specific treatment is most marked that the effect is visible, and in such cases the border error can be completely disregarded. Plots usually embrace 6 or 8 rows of cane, planted at from 4 ft. 3 in. to 5 ft. interspace.

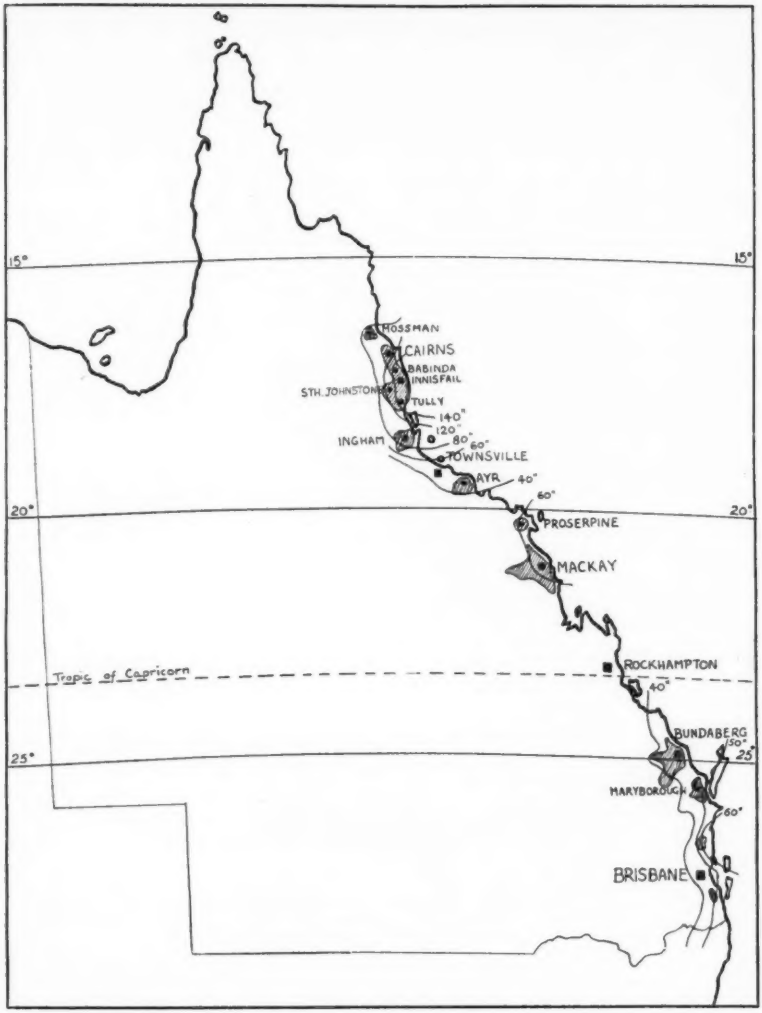

FIG. 1. Map of Queensland showing principal cane-growing areas (shaded), centres of population, and mean annual rainfall.

The results of the past four years have provided a very clear picture of the plant-food deficiencies of several of the most important soil types. The highly acid alluvial soils of the heavy rainfall areas show consistently marked response to dressings of phosphates, but no material increase is obtained from applications of potash. The deep, red volcanic loams are conspicuously deficient in potash, whilst phosphates have had but slight effects on yield. The red loams from schist have, however, behaved quite erratically with respect to these nutrients; in certain localities they have shown notable deficiencies of phosphate, whereas in others—perhaps less than a mile away—the increased yields are almost entirely due to potash. It does appear, however, that routine soil tests will be of assistance in this regard; results to date lend strong support to such a hope.

Practically all Queensland cane soils are notably deficient in nitrogen, and crops are benefited greatly from liberal dressings of nitrogenous manures. This is in keeping with the low organic-content of these soils. Sulphate of ammonia is the most highly favoured form of nitrogen, partly owing to price considerations but also to its superior storing qualities under humid conditions.

Advantage is frequently taken of the fallow period, following the plough-out of old ratoon fields, to plant a cover crop of legumes, which is turned under as green manure. Of the several species employed, two find particular favour. In the heavy rainfall areas, Mauritius bean (*Stizolobium* sp.) is especially suitable, owing to its prolonged growing period. In drier areas, Poone pea (*Vigna catjang*) is preferred, owing to its resistance to drought and to attack by the bean fly (*Agromyza phaseoli*), as well as to its more rapid growth. A satisfactory leguminous crop may provide for the needs of a heavy plant-crop of cane, but it is found that the subsequent ratoons will demand their full quota of sulphate of ammonia.

Following the qualitative fertility trials, quantitative experiments have recently been instituted. For this purpose the 5×5 Latin square is again favoured. With soils notably deficient in potash, the treatments are usually 0K, 1K, 2K, 3K, and 4K, where 1K represents 100 lb. per acre of muriate of potash. All plots receive a liberal basal treatment with respect to phosphate and nitrogen. For soils deficient in nitrogen and phosphoric acid, the treatments employed are: control, 1N 1P, 2N 1P, 1N 2P, 2N 2P; and all plots receive a uniform basal application of potash. Naturally, special care must be exercised in selecting uniform areas for trials of this kind; and again it is found that the experimental error may be kept at a surprisingly low figure when the necessary precautions are observed. The results in Fig. 2 (see p. 24) are typical of the data usually recorded.

All plots received 300 lb. superphosphate and 300 lb. sulphate of ammonia, the unit of muriate of potash being 100 lb. per acre.

The analysis of variance gives a value of S.D.M = 2·3 per cent., with the following mean yields:

Treatment	0K	1K	2K	3K	4K
Cane, tons per acre .	27·70	31·45	33·35	34·50	35·50
Cane, percentage mean yield	85·2	96·8	102·6	106·1	109·3

3K 33·75	1K 32·00	2K 37·50	0 25·00	4K 37·25
2K 31·00	3K 36·50	1K 36·00	4K 35·50	0 32·75
0 25·00	2K 35·00	4K 35·75	3K 34·75	1K 31·75
1K 29·25	4K 37·25	0 30·75	2K 31·25	3K 33·25
4K 31·75	0 25·00	3K 34·25	1K 28·25	2K 32·00

FIG. 2. Yields (tons per acre) of cane harvested from a quantitative potash trial on red volcanic loam.

That heavy fertilizer applications are necessary if maximum economic gains are to be recorded is amply borne out by trials to date, particularly those from the humid tropics. Thus at South Johnstone Experiment Station, the following appear to approximate to the optimum applications on the basis of present sugar values: sulphate of ammonia 200–500, superphosphate 900, muriate of potash 150; total 1,250–1,550 lb. per acre. The lighter dressing of nitrogen would apply to plant-cane, whilst second or third ratoons would demand the full complement. Failure to appreciate the necessity for consistently heavy applications of manure on soils of this type leads to disastrous results, as is brought out by the following yields, in tons per acre, of manured and non-manured second ratoons at South Johnstone: manured cane 36·5, unmanured cane 18·5; increase due to fertilizer 18·0.

The results gathered from all trials to date indicate definitely that the responses obtained on plant-cane will be repeated to a greater degree on the subsequent ratoons. Erratic returns for successive years are quite rare.

Trials at experiment stations are now confined to quantitative experiments, particularly those designed to show the relative value of different forms of manure, the influence of treatments on the sugar-content of the crop, or other special points. It should be noted that repeated trials have shown that sulphate and muriate of potash are of equal value for cane.

Utilization of By-products

The fertilizing value of by-products has received much attention during the past few years, and in particular interest has been focused on the utilization of molasses. This by-product has the following average composition, with respect to nutrients: nitrogen 1·0, phosphoric acid 0·3, and potash 3·0 per cent. Applied at the rate of 10 tons per acre, the added plant-food materials would amount to nitrogen 224, phosphoric acid 67, and potash 672 lb. per acre.

It might be expected that best results would follow the use of this material on soils deficient in potash. This has been demonstrated on the red volcanic loam, where a trial showed a total crop-increase for plant-cane and first ratoons of 33 tons of cane per acre. On soils which show

little response to potash, decided gains have again been recorded. Thus for plant-crops at Mackay and South Johnstone, harvested in 1932, the following increases were obtained:

Locality	*Molasses (tons per acre)*	*Cane-yield (tons)*		*Increased yield (tons)*
		Treated	*Non-treated*	
Mackay . . .	10	23·7	17·7	6·0
South Johnstone . .	10	41·3	28·4	12·9

By employing a 2-ton motor-truck fitted with a 400-gallon tank, it is found that the cost of transportation and spreading on the field can be greatly reduced, and the lands in close proximity to the mills are now being treated quite extensively with dressings of this by-product. The material is applied either to fallow land, or, in the drier areas, to blocks of young ratoons, with no apparent ill effects.

Filter-press cake and mill-ashes are also in great demand, particularly the former. Its effects on acid soils are especially beneficial and lasting. Ashes are valuable on red volcanic soils, particularly those from mills employing molasses as supplementary fuel.

Laboratory Soil Studies

In order to place laboratory chemical tests on a sound footing, an attempt has been made to correlate the results of simple and rapid methods with response in the field. The soil samples for this purpose are taken from the control plots of all fertility trials set out by the Bureau. The phosphate determinations have been made colorimetrically on soil extracts, employing 250 parts of N/100 sulphuric acid extractant to 1 part of soil. Available potassium is determined by leaching the soil with N/50 hydrochloric acid. Samples of moist soil, incubated for a period of four weeks, have been used to give a measure of the nitrifying power of the soil.

It is as yet too early to pass judgement on the above methods, but it appears that the degree of correlation will be sufficiently good to impart a definite value to these simple P and K tests. The nitrification studies are not at all satisfactory, and the results to date are confusing.

Many of the Queensland sugar soils are intensively acid and in need of liming. Field trials have been conducted in an attempt to determine, if possible, the correlation between pH and lime-requirement. It appears that the pH determined with a N/1 KCl solution is more informative than the value usually obtained with an aqueous suspension, and results indicate that the limiting value is approximately 4·5 by this method. Soils showing pH values below 4·3 may be relied upon to give increased yields from liming; soils less acid than 4·7 seldom show response. The rapid rate of lime removal under the heavy rainfall conditions at South Johnstone is demonstrated by the fact that the influence of 1 ton of burnt lime per acre cannot be detected chemically after three years, though the effect on the physical condition of the soil is more durable.

Soil Surveys

In 1930 a reconnaisance-survey of the major areas under cane was completed. The soil maps prepared at that time are extremely useful, though a more careful study will be required to smooth out certain existing irregularities. However, it is found that in certain of the cane areas where alluvial soils constitute the dominant type, the degree of variation in texture and composition over restricted areas is so great that only an intensive survey would be of value. This is particularly true of the Burdekin Delta lands.

Recent field and laboratory investigations have been confined to a thorough study of the moisture relationship of soils in the drier areas of the coastal belt, with special reference to the red volcanic loams. The results of these investigations expose further remarkable characteristics of these peculiar soils, particularly with respect to their low content of 'available' moisture. This is found to be restricted to the limits of 30 per cent. (field capacity) and 20 per cent. (when active growth of cane ceases). The importance of increasing the organic-content of these soils is clearly evident, and an intensive study is being made of economical methods of handling the most useful material available for the purpose—the trash and tops of the cane. It is the normal practice to burn the crop residues after harvesting, but it is confidently anticipated that the investigations at present under way will convince farmers of the wisdom of a policy of consistent trash conservation. These studies embrace both field and laboratory investigations.

Maturity Testing of Cane

Queensland canes enjoy the distinction of being the sweetest of all cane-growing countries, due in a large measure, no doubt, to the extremely favourable environmental conditions for maturing which normally prevail between May and October. In 1930 the phenomenal recovery of 1 ton of sugar from 6·83 tons of cane was recorded for the entire crop. It is felt, however, that even this figure could be appreciably improved by paying closer attention to the harvesting sequence on individual farms.

It is a well-established fact that the sugar-content of a cane crop will attain a definite peak at a certain period of its growth. This is the point at which the crop should be harvested for maximum returns; if harvested earlier or later the sugar percentage will be lower. It has been shown that the exact period of maturity may be determined by systematic analyses of canes selected from each field. If the stalks be divided into three equal sections, and the expressed juice from the composite samples of corresponding sections be analysed separately, it is found that, at maturity, the three analyses are approximately identical. The amount of reducing sugar in the juice is a particularly useful criterion of maturity, as this value tends to a constant minimum at this period, and rises after maturity has been passed.

Rapid colorimetric methods based on this determination have been devised, and the project of systematic maturity-testing has been adopted at several mills during the present season. It is thought that the average

sugar-yield of the cane may be raised by 0·25 to 0·50 per cent. if the present harvesting system is modified in conformity with the knowledge gained from these tests. This would mean an increased yield of 10,000 tons of sugar on the basis of the minimum figure quoted.

Plant-breeding and Disease-control

In Queensland there is such an intimate relation between these two activities that they are best considered together. This country has been particularly unfortunate in that the importation of cane varieties has resulted in the introduction of all but one of the major cane diseases. These, however, are not common to all areas, but the policy of cane-production in a country embracing a farming community of practically 8,000 individual growers precludes all attempts at successful eradication, except by growing highly disease-resistant varieties. In certain instances it has been possible to introduce suitable canes from overseas, but in others the onus has been placed on the plant-breeder to evolve high-yielding canes carrying the desired degree of resistance.

When plant-breeding was first instituted, in 1921, several very promising canes—such as S.J.4 and S.J.7—were evolved. The latter yielded, in preliminary trials, over 73 tons of cane and 11 tons of sugar per acre for a 12 months' crop; but unfortunately, its high susceptibility to leaf-scald disease was responsible for its rapid elimination. In 1928 a selection of the best breeding canes employed in Java was introduced to South Johnstone, and much attention has since been paid to the disease-resistance of the progeny from all desirable crosses.

The work is thus closely associated with the resistance-trials which the pathologists have evolved, and to which the selected canes are subjected as early as is practicable. Pathological investigations, with a view to devising methods of early mass elimination of susceptible seedlings, are at present under way.

In 1930 a breeding sub-station was established in the Cairns district, where a peculiarly localized area has been found in which flowering is exceedingly profuse, and where climatic conditions at that season permit of a greater yield of viable seed from cross-pollinations than is possible at South Johnstone. With the increased facilities thus afforded for the production of seed, the propagation of seedlings has been added to the duties of the Mackay and Bundaberg Stations. At each of these centres approximately 5,000 seedlings are planted in the field annually; at South Johnstone from 10,000 to 12,000 are propagated each year.

The pathologists of the Bureau have also carried out extensive studies on the nature of the major diseases and their mode of transmission. Quite recently they succeeded in establishing the fact that the insect vector of Fiji disease is the cane leaf-hopper (*Perkinsiella saccharicida*).[1] With respect to Red Stripe disease (*Phytomonas rubrilineans*), correlations have been established between the density of population of stalks and the degree of infection, whilst control measures based on time of planting and ratooning have also been devised. Several resistance-trials with respect to 'gumming' disease have been completed in the southern

[1] Bureau of Sugar Experiment Stations, Pathological Bulletin, No. 4, 1933.

areas, and from a large selection of imported canes a number have been secured which exhibit a high degree of resistance to the disease. These are at present undergoing trial to compare their yields with those of the older standard varieties, and it is confidently anticipated that certain of the new canes will prove of sufficient merit to warrant their propagation commercially. It would appear that this serious disease will very shortly be brought under complete control. An interesting phase of the pathological research work at present in progress is the effect of treating diseased cuttings with warm water. This is an important matter with respect to the transfer of small quantities of planting material to areas where the disease to which they have been exposed do not exist. The value of toxic ions has also received attention in this connexion, and the methods give promise of success.

Entomological Research

The two most serious cane pests are the 'borer' and the 'white grub'. The former is kept in effective control by the Tachinid fly (*Ceromasia sphenophori*), which was introduced from New Guinea in 1910. This parasite has become fairly well established in all northern areas where borer damage is recorded, and mass liberations of flies emerging from puparia collected in the field by the entomologists are made annually. Breeding-cages were also maintained for the purpose, but the field-collection method appears to be superior.

For grub control, soil fumigation continues to be the most effective treatment yet devised. A solution of paradichlorbenzene in carbon bisulphide is employed, and this is usually applied, by hand injectors, at the base of each stool on infected fields. The control is costly, but the expense is entirely justified in badly infested fields. Complete loss of crop is the result of neglect in this regard. Several parasites of the grub have been studied, but it would appear that little may be expected of biological control of this peat.

Recently an importation was made of parasitic flies (*Microphthalma michiganensis*) from Canada, in an attempt to effect control of the species of grub (*Pseudoholophylla furfuracea*) found in Southern Queensland. A good emergence of flies was reported, but they failed to breed in captivity. They were therefore released in suitable localities, but it is as yet too early to determine whether the parasites have established themselves.

Wireworms (*Lacon* sp.) are responsible for poor 'strikes' in many of the cane areas, and recent studies show that these are almost entirely associated with poor drainage of the infested blocks at the time of oviposition by the adult beetle. Where adequate drainage has been provided, one year prior to planting, the damage has been avoided. Trials on lands where cane-crops have not hitherto been possible have given a good stand following this treatment. Attempts to introduce repellents or poisons for this pest have been entirely unavailing.

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THE RATE OF SEEDING OF WHEAT IN RELATION TO VARIETY TRIALS

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1. *Introduction*

THE experiments discussed in this article were carried out with the object of testing a theory propounded by the senior writer after considerable thought on the problem of rates of seeding in variety trials and the perusal of the results of numerous experiments carried out in other countries, more particularly in Australia, on rates of seeding.

The theory was as follows: '*The rate of seeding of wheat may be in excess of the optimum by a reasonable amount* (*say, 20 to 40 lb. per acre*) *without the yield and quality of the grain being appreciably different from those resulting from the optimum seeding.*' The optimum is regarded here as the minimum quantity which will give the maximum yield under the existing conditions. The term 'quality' as used has no connexion with results from milling and baking tests, but with the value of the grain from the point of view of its acceptability for seed or by the milling trade.

In variety trials with wheat conducted by the Department of Agriculture from 1925–6 to 1929–30, the method used was to sow as nearly as possible equal numbers of seeds per acre of the different varieties. It was felt that this method was unsatisfactory as varieties having different habits of growth differ in their adaptability to various spacings, and although the seeding for one variety may reach or be in excess of the optimum under the existing conditions, that of another variety may be below the optimum, with the result that the recorded yield would be below the yield which would result from a more liberal seeding.

If, however, the theory stated above could be established as a general principle, its application to variety trials, as indicated below, would at least lessen the possibility of too low a seeding of one variety being a factor contributing to differences which might result between varieties. Obviously the optimum seeding for a variety will vary from season to season on the same soil and on different soils in the same season, and in the absence of definite evidence from experiments the decision as to what constitutes the approximate optimum must be arrived at from a consideration of farmers' practices.

The principle of sowing more than the optimum is applied in the following way. Since variety trials usually include a standard variety, the optimum for that variety is first decided upon. The rate of seeding adopted for *all* varieties is then the accepted optimum for the standard, plus 20–40 lb. per acre, or possibly more. Where it is the practice to

TABLE 1. *Seeding per acre, Ratios of Seeding to Plants per 10 ft. of Row and Yields*

Experiment, season, variety, &c.	*Treatment no.*	*Recorded seeding (lb. per acre)*	*Ratio of seeding (col. 3) to plants per 10 ft.*	*Yields (bushels per acre)*	*Remarks on yields*
1	2	3	4	5	6
1929–30 A. *Solid Straw Tuscan*			1 to:		
Sown: May 24, 1929	(1)	78·3	0·93	48·3	Treatments 2, 3, and 4 are significantly better than treatment 1, but do not differ significantly from one another
Harvested: Feb. 3, 1930	(2)	99·3	0·96	50·6	
	(3)	112·8	0·93	50·6	
	(4)	127·9	0·92	50·4	
B. *Hunter's*			1 to:		
Sown: May 23, 1930	(1)	81·0	1·17	52·0	Treatment 2 is significantly better than treatment 1. Treatment 3 does not differ significantly from 2. Treatment 4 is significantly better than all others
Harvested: Feb. 1, 1930	(2)	94·0	1·17	53·4	
	(3)	103·4	1·17	52·9	
	(4)	121·4	1·22	55·5	
1930–1 C. *Solid Straw Tuscan*			1 to:		
Sown: May 24, 1930	(1)	88·5	0·99	73·6	No significant differences
Harvested: Feb. 4, 1931	(2)	101·2	0·95	73·5	
	(3)	110·0	0·98	72·8	
	(4)	130·4	0·99	73·9	
D. *Hunter's*			1 to:		
Sown: June 16, 1930	(1)	84·0	1·08	47·3	The only significant difference is that between treatments 1 and 2
Harvested: Feb. 3, 1931	(2)	100·8	1·12	48·9	
	(3)	113·1	1·07	48·3	
	(4)	131·5	1·08	48·5	
E. *Marquis*			1 to:		
Sown: June 9, 1930	(1)	75·0*	1·01†	39·0	The only significant difference is that between treatments 1 and 4
Harvested: Jan. 23, 1931	(2)	99·6	1·12	40·2	
	(3)	114·6	1·14	40·7	
	(4)	130·8	1·13	42·1	
1931–2 F. *S.S. Tuscan*			1 to:		
Sown: May 16, 1931	(1)	81·8	0·88	24·7	Treatments 2 and 3 significantly better than treatment 1. Treatment 4 significantly better than all others
Harvested: Feb. 1, 1932	(2)	96·8	0·90	26·3	
	(3)	106·1	0·89	26·4	
	(4)	121·9	0·94	27·7	
G. *Hunter's*			1 to:		
Sown: May 14, 1931	(1)	83·4	0·80	27·8	Treatment 2 is significantly better than treatment 1, but yields probably unreliable as the crop was badly shaken by strong wind the day before cutting
Harvested: Jan. 25, 1932	(2)	96·4	0·77	29·4	
	(3)	117·4	0·75	28·5	
	(4)	131·2	0·78	29·0	
H. *Marquis*			1 to:		
Sown: May 15, 1931	(1)	83·0	1·03	16·9	Treatment 2 is significantly better than 1. Treatment 3 is not significantly different from 2. Treatment 4 is significantly better than all others
Harvested: Jan. 21, 1932	(2)	98·0	1·02	18·4	
	(3)	115·4	0·99	19·2	
	(4)	133·6	1·00	20·2	

* Error made in adjusting machine to sow the 85 lb. per acre required. † Disagreement with ratios for other treatments suggests error in recording seed sown. It is probable that rate of seeding was about 68 lb. per acre.

sow small quantities per acre, such as 45–60 lb., it is probable that the increase of 20 lb. per acre would suffice as against an increase over the optimum of about 40 lb. where 90–120 lb. per acre are sown normally.

2. *Details of Procedure*

I. Location of trials.—Experiments A and B (see Table 1) were carried out on the farm of the Canterbury Agricultural College at Lincoln. The remainder were conducted at the Canterbury Seed Company's farm at Leeston.

II. Selection of varieties.—Solid Straw Tuscan, the variety most commonly grown in New Zealand, and Hunter's, the next most common, were selected for trial in the first (1929–30) season owing to their sharply contrasting habits of growth. S.S. Tuscan is a vigorous upright grower from the commencement, whereas Hunter's makes rather slow growth and adopts a prostrate habit during early tillering and until rapid spring-growth begins. Both produce grain of a medium size, the S.S. Tuscan being rather larger than the Hunter's as a rule. In 1930–1 Dr. O. H. Frankel, of the New Zealand Wheat Research Institute, suggested including Marquis, a variety having a small grain and more or less intermediate in habit of growth between S.S. Tuscan and Hunter's, but more nearly approaching S.S. Tuscan in the early stages. Thus, fair extremes of early-growth form and seed-size were represented.

III. Size and arrangement of plots and replications.—In 1929–30 (trials A and B, Table 1, the sown plots were 3 chains in length and 7 coulter-rows (coulters 7 in. apart) in width, with a space of 14 in. between outside rows of adjoining plots. Twenty replications of each rate of seeding were sown in the order 1, 2, 3, 4, 1, 2, &c. At harvest all plots were divided into two by cutting out a strip $\frac{1}{3}$ chain wide across the experiments. This left two series of plots, each harvested plot being $1\frac{1}{3}$ chains in length, the yields and statistical errors being computed from the 40 sub-plots of each treatment.

In 1930–1 and 1931–2, following an alteration in the general design of cereal experiments, the sown plots were made 2 chains long by 7 coulter-rows wide, the space between plots being as stated above. Further, in order to reduce the liability to errors due to the possible presence of a fertility-slope from one side of the experiment to the other, plots were arranged so that 10 replications fell on each side of a middle plot, the order of the treatments being the same from the middle outwards, thus (M indicates the middle plot):

&c. . . . 2, 1, 4, 3, 2, 1 M 1, 2, 3, 4, 1, 2, . . . &c.

Plots were not divided at harvest, so that the yields and errors were computed from 20 replications of plots 2 chains long by 7 coulter-rows wide.

The sowing of each experiment was completed in one day, so that the influence of different times of sowing was minimized. The reader is referred to the *New Zealand Journal of Agriculture* for July, 1926, vol. 33, for a description of the methods of sowing and harvesting. The methods have not altered appreciably since that article was published.

TABLE 2. *Grains sown per 10 ft. of Row and estimated Field-germination, &c., in the 1931–2 Season*

Variety: bushel-wt., grains per lb.	*Treatment no.*	*Recorded seeding (lb. per acre)*	*Grains sown per 10 ft. of 7 in. row*	*Field-germination as % of grains sown*	*Germination in laboratory**		
					3 days	*6 days*	*9 days*
1	2	3	4	5	6	7	8
F. *S.S. Tuscan*							
Pounds per bhl. 60·4	(1)	81·8	108	67	13	94	98
Grains per lb. 9,824	(2)	96·8	127	68	..	..	..
	(3)	106·1	140	68	..	..	..
	(4)	121·9	160	71	..	..	..
G. *Hunter's*							
Pounds per bhl. 57·9	(1)	83·4	113	59	93	99	110
Grains per lb. 10,093	(2)	96·4	130	57	..	..	..
	(3)	117·4	159	55	..	..	..
	(4)	131·2	177	58	..	..	..
H. *Marquis*							
Pounds per bhl. 65·6	(1)	83·0	129	67	99	99	100
Grains per lb. 11,586	(2)	98·0	152	65	..	..	..
	(3)	115·4	179	64	..	..	..
	(4)	133·6	207	65	..	..	..

* Tests carried out by the Seed Analyst, Plant Research Station, Department of Agriculture, Palmerston North.

IV. Rates of seeding.—In the 1929–30 season the rates of seeding aimed at were:

Expt. A, S.S. Tuscan: 80, 100, 115, and 130 lb. per acre.
Expt. B, Hunter's: 75, 90, 105, and 120 lb. per acre.

Autumn and winter seedings of S.S. Tuscan are usually a little heavier than those for Hunter's, the latter being a little smaller in the grain as a rule and a freer tillering variety in the spring. The lowest rate of seeding adopted for each is probably a few pounds below the average of farmers' seedings.

In the following seasons 85, 100, 115, and 130 lb. per acre were the rates aimed at for all varieties. Care was taken to get as near as possible to the amounts stated. That the results were reasonably satisfactory is shown from a consideration of column 3 of Table 1.

The ratios of seeding to plants per 10 feet (column 4, Table 1) provide a fair measure of the accuracy of recording the rates of sowing. There was only one case of outstanding disagreement in the ratios for the different rates of seeding in each experiment (Expt. E).

V. Plant-counts.—One hundred counts, each a 10-foot length, were taken on each rate of seeding on the middle row when germination appeared to be completed and before active tillering commenced (5 counts on each plot). The results of these counts were used in estimating the field germination in Table 2, column 5. A trial of the uniformity of sowing of the drill used for sowing the experiments, and carried out by the Farm Implement Research Committee (in conjunction with Canterbury Agricultural College), showed that the average rate of sowing of the middle feed was within 1 per cent. of the average of all 7 feeds on the drill, so that the middle row on which plant-counts were taken can be viewed as being very representative.

VI. Weight of grain and bushel-weights.—Each plot was sampled as it was threshed and the samples from plots of similar treatments were bulked. From the composite sample from each rate of seeding, 20 lots each of 100 grains, selected at random, were weighed, broken grains being rejected. The results for the average weights of 100 whole grains and for the bushel-weights disclosed no significant differences, and therefore are not reproduced here.

VII. Statistical examination of results: (*a*) *Plant-counts.*—The errors associated with plant-counts were determined on a number of the treatments in the first two years merely to check the degree of precision obtained. The probable errors of the means were determined from the formula:

$$\text{P.E.}_m = 0{\cdot}67\sqrt{\frac{\sum d^2}{n\times(n-1)}}.$$

Eleven determinations showed the probable errors to range from 0·58 to 1·12 plants per 10 feet, indicating reasonably precise results from the method employed.

(*b*) *Yields.*—'Student's' method was used in computing the errors associated with differences in yield.

(*c*) *Weight of grain and bushel-weight.*—The errors associated with averages of these measurements were determined by using the formula given in (*a*). The averages of the twenty 100-grain samples ranged from 3·39 to 5·43 gm. per 100 grains, and their probable errors from 0·004 to 0·012 gm. The probable errors associated with the ten bushel-weight determinations ranged from 0·023 to 0·092 lb. per bushel.

The errors are not shown in the tables because the differences in weight per 100 grains or in bushel-weight are so small in all cases as to be negligible from a practical point of view; and there is an element of doubt regarding the validity of the differences in at least one or two cases. Although the weighing of all samples from an experiment was completed on the same day, the procedure adopted was to weigh the twenty samples from one treatment before proceeding with those of another. The results from Experiment E (Table 1) showed the grain from treatment 1 to be significantly different from that from treatments 2 and 3, although the grain from treatment 4, the heaviest rate of seeding, was heavier than that from 2 and 3 and not significantly different from that from treatment 1. In order to check the work, treatments 1 and 3 were again weighed, but in this case the weighing of a sample from treatment 1 was followed by the weighing of one from treatment 3 throughout. This resulted in weights of 3·383 and 3·381 gm. per 100 grains for treatments 1 and 3 respectively, a difference of only 0·002 gm. per 100 grains, or only about one-quarter of the P.E. of the difference between the samples. It was concluded, therefore, that the method adopted in the first place was liable to give incorrect results. It is possible that an unconscious bias in the selection of samples may have occurred, or that differences in humidity at the time of weighing of each affected the weight of the grain. The differences of the weighings from the original ones suggest that the latter explanation is the correct one. In view of the small differences in all cases it was considered that re-weighing of all the samples by the second method was not justified.

VIII. Evaluation of samples of wheat from different rates of seeding.—In order to obtain a practical judgement on the merits of the samples from the different rates of seeding in each trial, samples were classified by an experienced miller, Mr. J. Ireland, Manawatu Mills, Palmerston North, and by an experienced seed-grader, Mr. J. G. McKay, Department of Agriculture, Christchurch. The classification was based on the relative merits of the samples from each rate of seeding within each experiment, and neither judge knew the rates of seeding represented by the samples. The results of the judging show that the differences in value were insignificant.

IX. Field-germination.—In 1931–2 it was decided to measure the field-germination as accurately as the system of experiment permitted. Samples of the seed used for sowing were collected and the number of seeds per pound was determined by weighing, as described above. From this and the recorded seeding per acre the number of grains sown per 10 feet was estimated (column 4, Table 2). The number of plants per 10 feet, expressed as a percentage of the grains sown per 10 feet, represents the percentage of seed which produced plants (column 5, Table 2).

It seems not improbable that, given a high percentage of germination in the field, higher rates of seeding may not increase the yield, whereas with poor field-germination the higher rates may have an advantage under some conditions. As the field-germination cannot be predicted so as to allow seeding to be adjusted accordingly, the determination of the actual germination is likely to be of value only in so far as it may help to indicate, at least partly, the reason for differences on some occasions as opposed to absence of differences on others.

3. *Discussion of Results presented in Table 1*

I. Accuracy of recording seeding.—The ratios of seeding to plants per 10 feet of row (column 4) indicate reasonably small errors in recording of seed sown and counting of plants, with the exception noted in Experiment E.

II. Yields.—The yields of Experiments A, C, D, and G support the theory advanced in the introduction. The results from G are, however, of doubtful value on account of the loss of grain through shaking by wind prior to cutting, and will not be discussed further.

Experiments A and D show significant increases in yield of the second over the lowest rate of seeding, due to increases of 21 and 17 lb. of seed per acre respectively. The differences between treatments 2, 3, and 4 in each experiment are probably fortuitous. The second rate of seeding is about the optimum for the variety and conditions in each case, and increases of 29 and 31 lb. of seed for A and D respectively have not caused any material differences in yield from those of the optimum rate.

No significant differences occurred in Experiment C, and although treatment 3 shows the lowest yield, the next and highest rate of seeding has the highest yield. Assuming the lowest rate of seeding, 88·5 lb. per acre, to be the optimum—actually the optimum may be lower—increasing the seeding by 42 lb. over the optimum has not influenced the yield appreciably.

Experiments B, E, F, and H neither substantiate nor invalidate the theory because the optimum rate of seeding has not been exceeded. Each experiment shows a regular increase in yield with increased rate of seeding except for the third rate of seeding (treatment 3) in B. The increases from the lowest to the highest rate of seeding in seed sown and yields per acre are as follows:

Experiment	*Increased seeding*	*Increased yield*
B	40 lb.	3·5 bush. per acre.
E	56 ,,	3·1 ,, ,, ,,
F	40 ,,	3·0 ,, ,, ,,
H	51 ,,	3·3 ,, ,, ,,

These results are of interest because the highest rate of seeding was about 20–40 lb. in excess of the rate of seeding normally adopted by farmers, and suggest that the latter rate may be too low. However, this point is being investigated at the present time in a more extended series of trials.

The yields from Marquis (Experiments E and H) are of particular

interest because of the progressive increases in yield with increased rate of seeding with this small-grained variety. Experiment D, with Hunter's, was sown in the same field and immediately alongside Experiment E (Marquis) in 1930–1. The optimum rate of seeding for Hunter's under the conditions was about 100 lb. per acre, as no increase in yield was recorded with an additional 31 lb. of seed. Marquis having smaller seed than Hunter's gave the best yield for the rates of seeding tried, with approximately 131 lb. per acre, and as this was the highest rate used it is not certain that even at this rate the optimum was reached. The obvious conclusion is that size of grain is not a guide to the rate of seeding which should be adopted.

Dr. O. H. Frankel, Plant Geneticist, New Zealand Wheat Research Institute, has kindly supplied the following comment on the behaviour of Marquis relatively to the other varieties:

'In view of the fact that Marquis has given progressive increases in yield with each increment in the rate of seed, thereby differing from the other varieties in some seasons at least, it might be argued that this may be due to a lower rate of head-production per plant. That this is unlikely is indicated by the following data obtained from "Chessboard" trials under uniform conditions of spacing for all varieties:

	Number of ears per plant	
	1930–1	*1931–2*
Solid Straw Tuscan . .	3·46	4·25
Marquis	3·21	4·03
Hunter's II	2·60	3·36'

III. Weight of grain and bushel-weights.—The data show that the weight of the individual grains and the bushel-weight are not influenced to an appreciable extent by the rates of seeding adopted. Attention is drawn to the remarks in paragraph VII (*c*), section 2.

IV. Effect of rate of seeding on milling and seed-value of the resulting crop.—The significant point about the classification from the miller's point of view is that in no single instance is wheat from the lowest rate of seeding superior to that from higher rates. In point of fact the sample from the highest rate of seeding has been given a slightly higher value in five out of the six experiments.

In commenting on the relative merits of the samples from the point of view of their value as seed, Mr. McKay states: 'I have not attempted to value (on a monetary basis) any of the samples, as the differences (within each experiment), where they do exist, are so slight as to be negligible from a purchaser's point of view.'

Mr. Ireland considered that there were differences only in the amounts of broken grain and based his classification accordingly. The samples were not dressed.

Obviously, differences in rates of seeding have had no appreciable effect on quality as defined in the introductory remarks.

Comments on Table 2

Field-germination.—The field-germinations recorded in column 5 of Table 2 are probably lower than the average. The season (1931–2) was

particularly dry at the time of sowing and all wheat germinated very slowly, so that the plant-counts were taken late. The data presented in this column are from the second count for that season. At the time of taking a previous count, young plants were still coming through the ground; hence the second count was made when germination appeared to be complete.

4. *Conclusions*

The writers conclude that the evidence presented justifies the following statement being accepted as a general principle until such time as it may be proved incorrect:

'The rate of seeding of wheat may be in excess of the optimum by a reasonable amount (say, 20–40 lb. per acre) without the yield and quality of the grain being appreciably different from those resulting from the optimum seeding.'

Consequently the practice of sowing all varieties in variety trials at the same rate of seeding in pounds per acre and at a rate 20–40 lb. per acre in excess of the estimated optimum for the standard or control variety is considered to be justified. By so doing we feel sure that differences which may be due, in part at least, to insufficient seeding of one variety compared with another will be more nearly eliminated than where the approximate optimum is sown. The results from the small-seeded variety, Marquis, compared with other results presented, indicate that entirely erroneous results are likely to be obtained by the method of adjusting rates of sowing so as to provide equal numbers of seeds per unit area. Size of seed is no guide to rate of seeding.

So far as farmers' sowings are concerned, the results suggest that a little more, rather than a little less seed than that ordinarily used in Canterbury should be sown. (This point will be decided by a more widespread series of trials inaugurated in the 1932–3 season.) By so doing, there appears to be no chance of loss and a distinct chance of gain resulting from better yields without loss of value per bushel.

The trials did not provide good material for observations on the effect of rate of seeding on lodging, because there was no tendency to lodge in any of the trials except A. In this case it was noticed that the lightest rate of seeding, although there was no lodging, showed a greater tendency to go down than the heavier rates; the heaviest rate of seeding showing the least tendency in this respect. This is contrary to experience, and a reservation one would make to the advocacy of slightly heavier rather than lighter seeding is to except those districts where the crop is distinctly liable to lodge owing to excessive growth of straw.

Comments by Dr. F. W. Hilgendorf, Director, New Zealand Wheat Research Institute

'I consider the main conclusion fairly justified on the results. That it is not completely justified is owing to the fact that the small-seeded Marquis was not sown at a rate in excess of the optimum. The point that size of seed is no guide to rate of seeding is of greatest importance, and

the results furnish the best guide we have had to the conduct of seeding of variety trials.

'However, I believe that the whole investigation is elucidating not the best procedure as to seeding in variety trials but the best procedure under present faulty sowing of our grain drills.

'In Frankel's[1] hand-sown trials of rates of seeding, where the spacing was accurate, and where plants next to gaps were discarded, he found:

Spacing	*Equiv. in lb. per acre*	*Yield in grammes per unit length of row*		
		Tuscan	*Hunter's*	*Yeoman*
½ inch	177 lb.	266	270	234
1¼ ,,	73 ,,	247	268	263
2 ,,	44 ,,	246	253	253
4 ,,	22 ,,	283	261	268

'That 22 lb. per acre of any of the varieties should give about the same yield as 177 lb., or if this is not acceptable, that in Tuscan, 44 lb. should give the same as 73 lb., shows most clearly that thickness of sowing *per se* is not the cause of differences in yield, but that on the contrary almost any rate of seeding will give the same yield so long as the seeding is regular.

'Frankel thinks that this conclusion requires modification, and considers that evenness of spacing is not the sole factor in the above in producing evenness of yield, although he admits it is one cause. He considers that the thinly sown plants ripen more heads in the hand-sown plots than they would in field trials because of the inter-cultivation that the hand-sown plots receive, and says that Engledow agrees with him in this. Engledow's work on regularity of sowing reveals that the thicker sowings when a field is *drilled* give the better yields, because there are fewer foot-lengths on which there are no seeds. Where seed is drilled at a low rate innumerable spaces occur where there are no plants, the number of blank spaces decreasing with increased rate of seeding.

'I feel that one of the quickest ways of improving wheat yields is to improve our drills, and that when drills and drilling are perfect, thickness of sowing will become of much less importance than it is at present. In the meantime, however, the plan of heavy seeding of all varieties to counteract the imperfection of the drill, offers a practical solution of the difficulty of securing comparable seedings for variety trials.'

Summary

A series of eight experiments, using three varieties of wheat differing in growth-habit, has been conducted over a period of three seasons to test a theory propounded as a result of the perusal of data from numerous experiments carried out in other countries.

The theory was as follows: 'The rate of seeding of wheat may be in excess of the optimum by a reasonable amount (say 20–40 lb. per acre) without the yield and quality of the grain being appreciably different from those resulting from the optimum seeding.'

[1] N.Z. Wheat Research Institute: *First Annual Report*, December 1930, p. 52.

The plots of each treatment were replicated twenty times. The main conclusions are:

(1) Where the rates of seeding were in excess of the optimum, no appreciable differences from the optimum occurred in respect of yield, weight of grain, bushel-weight, and value of the grain for seed or trade milling.

(2) Size of grain is no guide to rate of seeding.

(3) In variety trials all varieties should be sown at the same rate in pounds per acre and the rate of seeding should be about 20–40 lb. per acre greater than the estimated optimum for the standard or control variety. By adopting this procedure it is considered that differences which may be due, in part at least, to insufficient seeding of one variety compared with another, will be more nearly eliminated than where the approximate optimum rate of the control variety is adopted for all varieties. The results indicate that entirely erroneous results are likely to be obtained by the method of adjusting rates of sowing so as to provide equal numbers of seeds per unit area.

(4) The Director of the New Zealand Wheat Research Institute, commenting on the results, expresses the opinion that improvement in grain drills is an important factor in improving wheat yields.

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THE VEGETATIVE PROPAGATION OF CACAO

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Historical introduction.—Credit for the first successful attempt on record to propagate cacao asexually belongs to J. H. Hart, who in 1898 exhibited before the Agricultural Society of Trinidad and Tobago several plants grafted by approach (inarched) on seedling stocks. From that date onward the literature bears witness to a lively interest in the subject in several cacao-growing countries.

In Dominica, J. Jones [1] succeeded with the same grafting method in 1906, after attempts in the previous year to graft cacao scions on *Theobroma bicolor* had failed. Parenthetically it may be mentioned that later attempts to use *Th. bicolor* as a stock for cacao have failed in Trinidad and Surinam, and there are no records of success elsewhere.

Meanwhile in Jamaica, Harris [2] had demonstrated in 1903 the possibility of another method, by patch-budding on vigorous sucker shoots from the bases of old trees. In Java, Heyl, according to van Hall [3], budded cacao at about the same time, and van Gent later tried various methods of grafting and budding. In Haiti, Casse [4] had success in 1906, budding on young trees $1\frac{1}{2}$ to 2 years old, and 0·5 inch or more in diameter. In the Philippines, Wester [5] in 1911 had good results with shield-budding on seedling stocks 20–25 mm. in diameter.

Jones [6], in reporting later experiments in Dominica, advocated trials of budding on young seedlings, to obviate the erection of staging round the parent tree, as in inarching, and to enable the whole process to be carried through in a nursery. In 1915 he reported success in budding on seedlings in bamboo pots [7].

In Trinidad work had been independently following lines similar to those in Dominica, and in 1913 Freeman [8], reviewing past efforts to bud cacao, reported successes by J. C. Augustus with sixteen plants in bamboo pots out of forty attempts. By the next year the Trinidad Department of Agriculture had established the technique sufficiently to warrant the laying down of an experiment to compare budded, grafted and seedling trees from the same parents under plantation conditions. Details of the experiment are given by Freeman [9]. It involved the planting of 4 acres of vegetatively propagated trees, which are still extant and interesting as the first trees of such a nature ever planted on any considerable scale. A little later, another experiment was laid down to compare methods of replacing poor bearing trees in established fields, and one of the methods included was to cut the poor bearers down close to the ground, and bud on the suckers developing from the stump. Williams [10], in 1917, had excellent results from budding on suckers, the rate of growth of the buds being 6 inches a month. Subsequent experience, however, revealed a tendency for the suckers to break away from the stump, which led to the abandonment of the method for plantation purposes.

In Surinam, Stahel has evolved a budding technique which is described by van Hall (loc. cit.). It differs from that used in Trinidad in the employment of larger stocks and a different type of bud. In general, budding has everywhere supplanted grafting as a more convenient and economical method.

It is noteworthy that all the investigators contributing to the perfection of the budding technique in different countries were inspired by the advantages to be derived from the cultivation of uniform types of cacao, in place of the heterogeneous seedling populations which are still the rule. Some mentioned earlier bearing as an additional point in favour of budded trees, but all stressed uniformity, and especially uniformity of high yielding power, as the great desideratum.

In quest of uniformity all attempted, quite rightly, to adapt to cacao horticultural methods long established for temperate orchard crops; but in quite recent years temperate orchard practice in this respect has again moved ahead. Researches, in which the East Malling Station has taken a leading part, have shown that uniformity of yield and of other characters in temperate fruit trees depends on uniformity of rootstock as well as uniformity of scion. There is no reason *a priori* to suppose that these findings will not apply to cacao, but rather the reverse.

For this reason, when in 1930 a Cacao Research Scheme was launched at the Imperial College of Tropical Agriculture, it was felt necessary to approach the problems of vegetative propagation from a new angle. There were many problems relating to budding still awaiting solution, but it was decided to concentrate attention, so far as the propagation side of the programme was concerned, on efforts to raise cacao trees vegetatively *on their own roots*. The numerous problems of stock-scion interactions could the more profitably be deferred for later attack because in the absence of clonal rootstocks the most promising instrument for their solution was not yet available. A summary of the results achieved and of the present outlook is the object of this paper, but, in order to explain the terminology which must be employed, a brief description of the mode of branching of the cacao tree must be given first.

Branching of the Cacao Tree.—A young cacao seedling growing healthily produces a single vertical unbranched stem, on which the leaves are arranged in a 3/8 spiral, and which later forms the *main trunk* of the tree. After a variable time, and presumably when it has attained a certain physiological condition not yet defined, the terminal bud divides into three, four, or five, which grow out into oblique or almost horizontal branches (Fig. 1). The whorl of branches so formed is known as the *fan* or by the Trinidad term *jorquette* (pronounced *horkette*), the latter name being preferable, because the word *fan* or *fan-branch* can then be used for the individual limbs of the jorquette without danger of confusion. The fan branches have their leaves in two ranks, and bear secondary branches of higher orders, all with leaves in two ranks.

At a later stage a vertical branch arises from the main trunk just below the jorquette. Since it arises on old wood, there is difficulty in determining its exact origin, but it is probably axillary. This branch is known as a *chupon*; it has its leaves in a spiral, and it repeats exactly the behaviour

of the seedling axis, growing up through the jorquette and in due course branching into a second jorquette some feet higher. A third and fourth tier may be added to the tree in the same way. The arrangement is often obscured in old trees by loss of the lower branches, by reduction of the

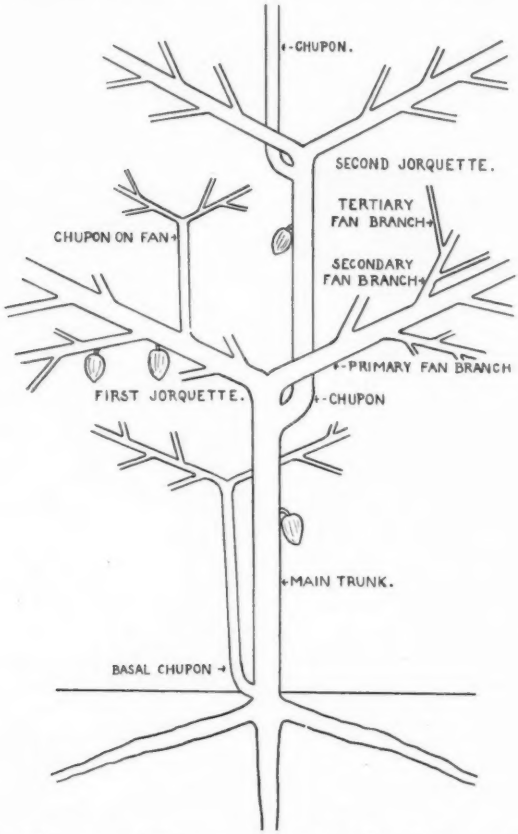

FIG. 1. Diagrammatic Representation of the Branch System of Cacao.

vertical part of one 'storey' so that two jorquettes arise from almost the same point, or in other ways, but it can usually be traced on careful examination.

As the tree grows older, it nearly always produces from the base of the trunk, at or near ground level, additional chupons (also referred to as 'suckers', 'water-shoots', or 'gormandizers') and if left untended may develop into a clump. In cultivation these basal chupons are most commonly cut out, though some planters like to leave two or three. If the original tree is showing signs of disease or senility, it is usual to allow a strong chupon to grow, and when it is in a condition to replace the old

trunk to cut out the latter instead. For this reason 'age' in cacao fields is a complex subject, since an old tree, said to be of a certain age, may have been renewed (so far as the parts above ground are concerned, and probably in roots as well) several times since the actual planting.

Normally chupons do not branch, except when they make their jorquette, but they may be induced to do so by bending them over or cutting them back, and when the axillary buds are thus stimulated into growth they give rise in every case to branches of the same type, i.e. to chupons. Fan branches on the other hand branch freely, and their axillary buds likewise normally produce shoots like themselves, i.e. fan branches of the second or higher orders. If, however, fan branches are cut hard back they will sometimes produce chupons behind the cut. Moreover, it is by no means uncommon in the field to find chupons arising from fans, and although the physiological equivalent of pruning, in the shape of a wound or canker, can often be found as the cause, such is not invariably the case.

The so-called 'dimorphism' of cacao branches is thus clearly marked, yet by no means absolute, and there seems to be a certain plasticity of behaviour in both kinds of buds. Buds on fan branches (*fan buds*) especially seem able to give rise to either fans or chupons, according to their physiological state, and shoots may be found on fan branches having a spiral phyllotaxis below and a two-ranked arrangement above. Axillary buds on chupons are less plastic, but physiological factors must certainly determine the height at which the terminal chupon bud produces its jorquette, since that height varies without any apparent morphological or genetic reason.

The practical importance of the dimorphism in propagation lies in the fact that the entire habit of the vegetative progeny depends on the type of branch or bud used. Thus in the early grafting experiments, fan branches were inarched on seedlings held in bamboo pots near the tree, and Jones describes his grafted plants as branching a few inches above the point of union and forming bushy specimens. In the budding method described as used in Jamaica and Haiti, trees were pruned to provide vigorous chupons for budwood and the result, as shown by Casse's photographs [4], was that the budded progeny developed a main trunk. The same applies to Stahel's technique, in which chupon buds are recommended as preferable. In Trinidad, however, fan buds have usually been employed, and as a result budded plants can be recognized at a glance by their lack of trunk, and by their spreading, two-ranked branches, which need some training to make a symmetrical tree. It is to be noted that whereas there is always an abundance of fan material available on a healthy tree, there is very often, under plantation conditions, little or no chupon material to be had without recourse to manipulation. Exactly the same considerations apply in propagation of scions on their own roots.

Propagation by Cuttings

The rooting of cacao cuttings has possibly been achieved, though unrecorded, many times in different countries, but it has never previously

attracted attention as an important contribution to the technique of crop improvement. Since the end of 1930, however, a systematic survey of the possibilities of the method has been made by E. E. Pyke, working in these laboratories, and the conclusions here given are based entirely on his researches. Detailed accounts have appeared elsewhere [11, 12] and only a summary will be attempted.

The work began with a general survey of all possible means of vegetative propagation, excluding budding and grafting. This included trials with hardwood and softwood stem-cuttings and root-cuttings, and soon demonstrated beyond doubt that between those the greatest hope of success lay in the use of softwood. By 'softwood' is meant shoots that are mature but which still retain their leaves, and which are set to generate a root-system without removal or loss of those leaves; in actual texture such shoots are semi-hardwood. The success with this kind of cutting was of such an order that there appeared to be no possible economic advantage in pursuing investigations with hardwood, and subsequent work was devoted to standardization of method.

The second year's work established several principles. In the first place it showed an important connexion between the physiological condition of a tree and the behaviour of cuttings taken from it. Old trees and trees grown without shade are alike unsuitable for supplying cuttings. The general appearance of shoots likely to root well is now known, but much physiological research remains to be done before the constitutional features of such material can be defined. In the second place comparisons were made between chupon cuttings and fan cuttings, which showed little difference in ability to root, but marked differences in the type of rooting and subsequent growth. In both, the roots push horizontally through the cortical tissues just above the callus, but whereas in fan cuttings they continue to grow almost horizontally for some centimetres, in chupon cuttings they usually turn vertically down as soon as they emerge from the stem. In fans, the terminal bud, if present, usually grows out, together with several lateral buds, sometimes low on the stem, and the shoots tend to spread obliquely (Plate, Fig. 1). In chupons, on the other hand, either the terminal bud, or in its absence a single lateral near the top of the cutting, grows out into a vertical leading shoot. The differences are illustrated by Fig. 2. The chupons, as might be expected, approximate more closely to seedlings in their behaviour, and the importance of that fact will be indicated later.

The essence of success with softwood cuttings lies, as every horticulturist knows, in keeping the leaves on until roots are formed, and to that end careful control must be exercised over both the water-content of the rooting medium and the humidity of the air above. Illumination is also important, since much of the carbohydrate used in root-formation is presumably manufactured by the cuttings after they are set in the propagator. Temperature under Trinidad conditions needs no elaborate control, and none was attempted, since the object of the researches was less to discover academically optimum conditions than to establish the simplest technique consistent with practical results.

Full details of the propagating frames used and of the environmental

factors studied are given by Pyke (loc. cit.). In average batches of cuttings, 50 per cent. root within three weeks, and good batches finally show 90 per cent. or more of successes. These figures justify the claim

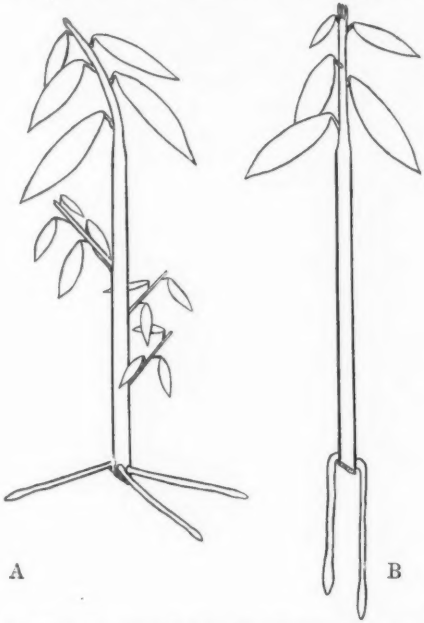

FIG. 2. A. Typical Fan Cutting. B. Typical Chupon Cutting. (New growth only shown; old leaves omitted for simplification of diagram.)

that a practicable technique has in fact been found. Subsequent treatment needs care if the rooted cuttings are to be successfully established in the field, but presents no very great difficulties.

Propagation by Layering

Stooling and layering were tried simultaneously with the experiments on cuttings, and with equal success.

Aerial layering, or marcotting, in which ring-barked branches are surrounded by a ball of moist soil in sacking, has been found possible with cacao in Trinidad, Ceylon and Java, and is illustrated by van Hall (loc. cit.). It is, however, a tedious method, and for large-scale work possesses no apparent advantages over the setting of cuttings.

Pyke obtained excellent results by pegging down seedlings about 18 months old on the surface of the soil. Basal chupons of older trees, if they occur in a suitable position and are at the right stage, can be treated similarly. Under such treatment several of the axillary buds push out into vigorous chupon branches, and if they are then moulded up with soil they develop in a few months a strong root-system with one or more main roots running vertically down like tap-roots (Plate, Fig. 2).

Earthing-up must be deferred until the buds have made some growth, because cacao buds apparently will not burst when covered, and all attempts with covered layers failed. Secondary layers were at a later date made from the first with equal or even greater ease.

The observations are still incomplete in the sense that established cuttings have not yet been layered, that step being on this year's programme, but there appears no reason why chupon cuttings at least should not behave exactly like seedlings in this respect. Fan branches similarly laid down have so far given rise to fan-type layers, and fan cuttings may be expected to do the same. It is in layering of fans, however, that the plasticity of the buds assumes importance. It is most probable that by cutting hard back after rooting, or by some other manipulation, chupons can be induced on fan layers. Work is at present being directed towards finding the appropriate treatment for converting fans into chupons with certainty.

The possible advantages of layering lie chiefly in the ease of the process, and the fact that constant daily attention is not required by a layer-bed, as it is by a propagating frame set with cuttings. On this account the layering technique may prove more adaptable to estate routine, and provide a means for the planter to bulk up an approved clone from rooted cuttings initially supplied by an experimental station. The possible disadvantages are the length of time required for rooting and the rather large space taken up by a layer nursery as compared with a seedling nursery. Much remains to be discovered about the minimum time in which layers can be induced to root, and also about the number of rooted branches which can be obtained per unit length of stem laid down. Until these points are determined the method can neither be recommended for commercial use, nor accurately compared with the cutting technique in efficiency and practicability. Still, from the point of view of practical nursery multiplication, the outlook is the more promising for the existence of these alternative methods.

Stooling by a method similar to that used for Malling apple stocks has been tried, but so far has given results inferior to those from layering, chiefly because the shoots seem to need ring-barking to induce deep rooting, and the extra handling involved has no compensating advantage. It remains to be seen whether older stools will behave differently, and no final pronouncement on the relative merits of the two methods is yet possible.

Established potentialities.—With the striking of cuttings and rooting of layers added to the previously established method of budding, there is now at the disposal of the research worker an almost complete range of possibilities of producing any kind of tree he chooses. A tree selected in the field by the plant-breeder as worthy of clonal multiplication may be grafted or budded on a seedling stock, or cuttings or layers may be taken from either its fan-branches or its chupons, according to the circumstances, the facilities and the type of material most readily available on the tree. Once established in the experiment station, any type of tree can be converted into almost any other. Grafts or buddings can be subsequently layered or used as a source of cuttings. Chupon-type plants will

always produce sooner or later a jorquette of fan branches. The only gap in the chain is the absence of a sure method for obtaining chupons at will on fan-type plants, and it has been shown that this problem does not seem by any means insoluble. In short, isolation of any desired clone *on its own roots* becomes a matter of routine, and the main question next for solution is, which of the several methods of propagation available can be most advantageously adapted to the raising of planting material on a commercial scale. This question, however, involves at least three subsidiary ones of the greatest importance, which must be shortly discussed.

Outstanding Problems

Ruling out grafting, which by the consensus of opinion of previous workers is less convenient than budding if seedling stocks are to be used, and ignoring any possible differences between cuttings and layers as means of propagating clones on their own roots, there are still six distinct kinds of vegetatively propagated cacao trees which now need careful study and comparison. They are illustrated diagrammatically in Fig. 3, which represents, from left to right:

Type I A, fan bud on seedling stock; I B, chupon bud on seedling stock.
Type II A, fan bud on clonal stock; II B, chupon bud on clonal stock.
Type III A, fan layer; III B, chupon layer.

The three major questions to be answered, in order of importance and urgency, are: (i) Should the root-system be of seedling or of vegetative

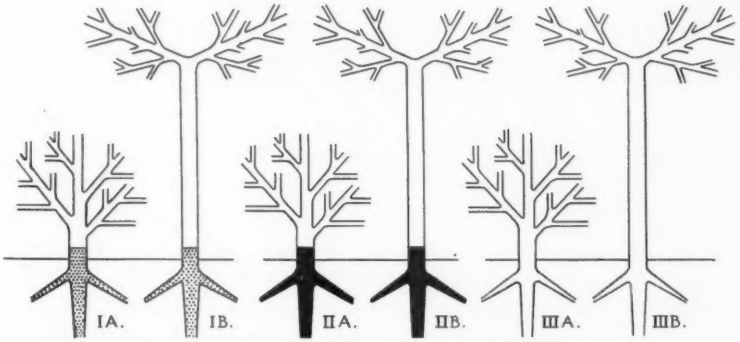

FIG. 3. Types of vegetatively propagated Cacao trees:
I. Budded on seedling stock. A. Fan bud. B. Chupon bud.
II. Budded on clonal stock. A. Fan bud. B. Chupon bud.
III. Unworked. A. Fan cutting or layer. B. Chupon cutting or layer.

origin? (Type I versus Types II and III.) (ii) Should the root-system and the scion be of different genotype or identical? (Types I and II versus Type III.) (iii) Should the scion be of fan or chupon origin? (Sub-type A versus sub-type B throughout.) Only experiment can provide the answers, and it may well provide different answers under different sets of conditions. There are, however, a number of considerations bearing

on each of the questions which must be reviewed even at the present stage, because they indicate the relative magnitudes of the issues involved.

(1) *Root-systems.*—The drawbacks of seedling stocks for temperate fruit trees are too well known to need more than mention. They arise from the fact that the parent trees from which the seedlings are raised are heterozygous, so that the seedlings themselves vary in constitution one from another, and the composite trees of which they form part after grafting or budding must likewise vary. The variations in yield and in other physiological behaviour of uniform scions when united with such variable stocks are of great economic significance, and it has come to be realized that if orchard material is to be truly standardized, stocks raised vegetatively must be used.

Similar drawbacks of seedling stocks for cacao are at present only assumed by analogy. Seedling cacao stocks are indubitably heterogeneous, and the argument by analogy is justifiable as a working hypothesis until disproved. A direct demonstration is difficult, first because there is so little budded cacao of which records have been kept, and secondly because there have until now been no clonal stocks to serve as standards of comparison. What little direct evidence there is does not contradict the hypothesis. Still, the direct demonstration must be provided before further work can be well and truly founded on a scientific basis.

On the other side of the account, there is a strong prejudice in many quarters in the tropics against trees on non-seedling root-systems. It is said that the absence of a tap-root makes them liable to fall in wind and otherwise militates against their efficiency. Such an argument must be respected and put to experimental test. That it may be true, yet only half true, is shown by Fig. 2, illustrating the essential differences which may arise among vegetatively induced root-systems themselves. At the present it seems likely that cacao stocks raised from fan cuttings or fan layers might be genuinely open to objection, whilst those raised from chupon cuttings or chupon layers might not. Steps are being taken immediately to compare both types very carefully with seedlings, but it must inevitably be some years before conclusive results can be obtained, and meanwhile other investigations must be pushed ahead on the presumption of an answer favourable to clonal stocks.

(2) *Composition of tree.*—Assuming for the purposes of argument that vegetative stocks can be proven better than seedlings, the question at once arises whether budding remains any longer necessary or desirable. Budding of selected scions on selected clonal stocks would be directly analogous to the most advanced practice in temperate fruit culture, but it need not necessarily prove ideal for cacao, and this is a case where argument from analogy can easily be carried too far.

Cacao trees selected for propagation will usually be selected primarily for high-yielding power, and only secondarily for qualitative characters of the fruit. In this respect they are not quite comparable with fruit varieties, which have probably in most cases been selected primarily for non-yield characters such as flavour, texture, or size of the individual fruit, and only secondarily for yield per tree. The high-yielding cacao tree must have a root-system capable of supporting its yield, and if

cuttings or layers from it regenerate a root-system of similar type, the main object of vegetative propagation will be attained.

It is not overlooked that a scion good on its own root-system might give even better results than its parent if placed on another; neither have the possible uses of different stocks to change the habit of the scion been forgotten. Dwarfing stocks, for example, might be very valuable for 'filler' trees in laying out new plantations at a wider spacing of the 'permanent' trees. There is, indeed, scarcely any limit to the amount of research which will be needed into the interaction of stocks and scions in cacao culture, now that clonal stocks are available for accurate studies.

At the same time there is a factor of quite another kind which cannot be excluded from this part of the discussion, and that is disease. Canker (caused by *Phytophthora Faberi* Maublanc) is one of the most destructive of diseases of cacao, and causes incalculable losses. It is one of the advantages of the seedling cacao tree that, should the main trunk or jorquette be badly attacked, the whole system can be regenerated by allowing a basal chupon to grow, and it has been pointed out above that this practice is regularly followed. A budded tree naturally cannot be regenerated in similar fashion, because if a basal chupon grows it is of the stock and not the scion variety. A tree from a layer, however, will behave in this respect like a seedling. The natural regenerative power of the cacao tree is a valuable economic asset not shared to the same extent by the majority of species usually budded or grafted, and may possibly prove the deciding factor between 'foreign' and 'self' root-systems, at least in many districts where canker is especially rife.

(3) *Branch-systems.*—It has already been hinted that if layers (Type III) should ultimately prove the most satisfactory means of propagation, as on the balance of available evidence seems not unlikely, the choice between fan and chupon material for multiplication is likely to be decided by the nature of the respective root-systems. If, however, trees of Type I or Type II prove preferable, the question of branch-systems will add itself to the more urgent ones already discussed.

On account of the cauliflorous habit of cacao, if a main trunk is required on a budded tree it must be obtained from a chupon bud set low on the stock. The alternative method of budding high with a fan bud and allowing the stock to form the trunk is impracticable, because the stock would then bear fruit, and the crop would be only partly derived from the scion variety. Consequently, the choice of bud seems to be essentially a choice between presence or absence of a main trunk, and this would appear to depend more upon the tastes of the planter and the kind of cultivation he intends to give the trees than upon fundamental botanical considerations. Sub-types IA and IB are already both grown on a small scale with success, and whilst there is undoubtedly scope for experiments to compare the two, the problem seems both less urgent and less difficult than either of the two foregoing.

The transmission question.—In conclusion, reference must be made to a problem omitted from the main discussion in order to clarify the issues, but inseparable from any study of vegetative propagation in cacao. Harland [13] concluded, in 1924, from records of yield of budded trees kept

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by the Trinidad Department of Agriculture, that 'the yield of a tree affords no criterion whatever of the sort of budded offspring it will produce and the value of a tree for budding purposes must be assessed in terms of the mean yield of its budded offspring'. In 1928, from analysis of fuller data, he upheld his conclusion, and said: 'A heavy bearing tree may transmit heavy yield to its budded offspring. On the other hand it may absolutely fail to transmit and may give rise to trees which are much worse than the average. There is no method of telling whether a tree will transmit heavy yield either to its budded or seedling offspring except by testing it' [14].

A similar state of affairs is well recognized in the commercial budding of rubber, and its causes are imperfectly understood. Many possible causes suggest themselves, some of which concern compatibilities between stocks and scions, but discussion of them here would be out of place. It is evidently of prime importance to determine whether similar irregularity of transmission occurs when propagation is done by cuttings or layers, and the determination may profoundly affect not only the choice of technique to be employed, but even the whole future of vegetatively propagated cacao.

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FIG. 1. An established softwood cutting

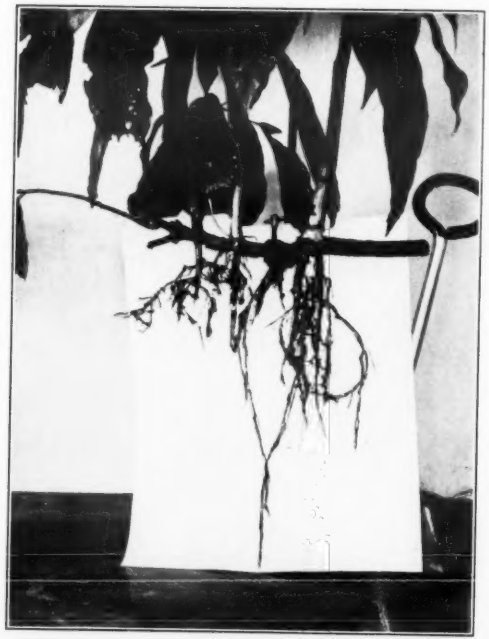

FIG. 2. Chupons rooting from a layer

(*Photographs by E. E. Pyke*)

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THE RELATIVE PALATABILITY OF SEEDS-MIXTURES, AND A STUDY OF THE INFLUENCE OF FERTILIZERS ON NATURAL HILL PASTURES

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THE investigations into the palatability of herbage plants conducted at the Welsh Plant Breeding Station on species grown in pure plots has led to the further stage of investigating the relative palatability of mixtures composed of a selection of these species. Researches have already been carried out on these lines in respect to the individual species existing in newly sown and in permanent swards [1], and it has been shown that grasses, clovers, and miscellaneous species are differentially selected by the grazing animal from among the mixture of species which comprise them. The first part of the present paper relates to comparisons between the relative palatability of mixtures designed for the purpose of such a study.

In the second part of this paper an account is given of the effect of artificial fertilizers and lime on the palatability of three types of natural upland pastures. That manures have an influence on the grazing of swards is well known, and comments are frequent as to the partiality of stock for fields, or portions of fields, that have received fertilizers. The data here discussed have been obtained in connexion with experiments designed to investigate the methods of improvement of upland grazings undertaken by the Station.

PART I. *Material and Methods*

For the investigation into the relative palatability of seeds-mixtures, a trial (E 138) was sown on the Quarry Flat Field of the Station. This field, which had been under oats in 1930, received a dressing of lime at the rate of 2½ tons per acre in January 1931, and a dressing of basic slag at 5 cwt. per acre at the time of sowing the seeds in the present trial. Sowing was carried out in May 1931 without a nurse crop, and an excellent 'take' resulted. The experiment consisted of a series of 1/120th acre plots comprising 18 mixtures and a certain number of pure plots. Four replications of the mixtures were used for the palatability trial, and of the plots of pure species three replications were sown as pure plots and three with a seeding of 2 lb. per acre of wild white clover (*Trifolium repens* L.). The field was hurdled into paddocks to allow of controlled grazing on the several types of plots, and also to enable light and heavy degrees of grazing to be carried out.

The method of obtaining the relative palatability data was to allow a flock of sheep to graze freely among the plots within a paddock. Relative marks according to the amount of growth and the composition of the herbage in each plot were assigned prior to the grazings. After the flock had grazed for a period determined by the number of sheep and the

quantity of herbage offering, relative marks were again allotted according to the degree of selection.

Seven grazings were made throughout the trial, the first in May 1932 after a year had elapsed to enable the plants to become established. The subsequent grazings were taken at three-weekly to four-weekly intervals. The difference in the degree of grazing of lightly versus heavily grazed paddocks was that the latter paddocks had double the number of sheep-hours at each grazing. In consequence of this, the herbage on these areas was shorter, finer leaved and freer from inflorescence-stems than that of the lightly grazed areas.

The compounding of the 18 mixtures consisted of interchanging and adding species to very simple mixtures. By building up mixtures in such a manner, and studying any selective grazing among them in conjunction with that among the pure plots of the same species which formed the mixtures, it was thought that considerable advantage would accrue in the interpretation of the data.

Results

1. *Pure plots.*—The species used in the mixtures were sown separately as pure plots and again as pure plots with wild white clover, as mentioned above. It transpired, however, that wild white clover very quickly made a voluntary appearance in the plots where no seed of this species had been sown, and by the first harvest year there was little difference in the content of white clover on both sets of plots. In consequence of this, the plots have been considered as one unit in this respect.

The data for the percentage of white clover in the herbage, with the exception of the pure plot of white clover, together with the relative amounts offering and eaten of the total herbage of each plot are presented in Table 1.

TABLE 1. *Relative Amount of Herbage Offering with the Percentage of Wild White Clover Present, and the Relative Amount Eaten from Six Single Species Plots under Light- and Heavy-Grazing Conditions*

Species	*Light grazing*			*Heavy grazing*		
	Per cent. clover present	*Total herbage offering*	*Total herbage eaten*	*Per cent. clover present*	*Total herbage offering*	*Total herbage eaten*
Perennial rye-grass						
Kentish . . .	11	9·9	7·5	12	9·4	7·4
Timothy, indigenous .	15	7·2	9·9	14	7·5	8·5
Cocksfoot, indigenous .	12	10·0	8·1	11	10·0	8·0
Rough-stalked meadow-grass, commercial .	27	6·6	9·3	15	5·8	7·2
Red clover, Montgomery . . .	6	6·9	10·0	6	5·1	10·0
Wild white clover, Kentish indigenous .	..	6·4	9·7	..	4·3	9·4

Examination of the data in the table indicates that the largest amount of herbage under both systems of grazing has been produced by cocksfoot (*Dactylis glomerata* L.); the yield of perennial rye-grass (*Lolium*

perenne L.) has been very nearly as high. Timothy (*Phleum pratense* L.) has occupied an intermediate position between these two species and the remainder. Rough-stalked meadow-grass (*Poa trivialis* L.) and the two clovers have offered to the sheep less herbage in relation to the other species under hard-grazing conditions than under light-grazing conditions.

In respect to the relative amounts eaten, the hardest grazed plot in both sections has been that of red clover (*Trifolium pratense* L.). The plots of timothy, rough-stalked meadow-grass, and white clover have been eaten to only a slightly smaller extent under light-grazing conditions, and the same applies to white clover in the more heavily grazed plots. There is a similarity in the amounts eaten of perennial rye-grass, cocksfoot, and white clover in relation to red clover under both systems of grazing. The relatively larger amount eaten of rough-stalked meadow-grass under light-grazing conditions compared with that of red clover, although the amounts offering of both species were practically similar, may possibly be accounted for by the high percentage of white clover in the lightly grazed plot of that grass.

In general, the two clovers have shown themselves to be more palatable to the sheep than have the grass plots containing a certain amount of wild white clover in their herbage. The latter plots have shown timothy to be the most palatable, and cocksfoot to be more palatable than perennial rye-grass, whilst the perennial rye-grass and rough-stalked meadow-grass plots were of equal palatability when the white-clover content and the degree of grazing were similar.

2. *The mixture plots.*—Data regarding the blending of the species in the mixtures and their seedings in pounds of viable seed per acre are presented in Table 2; the data on the botanical composition of their herbage in terms of relative productivity determined prior to the grazings have been averaged for the grazings and are given in Table 3.

The data in these two tables show that perennial rye-grass has greatly suppressed the timothy and cocksfoot, as shown in mixtures 1 and 2, 13 and 15, 16 and 18. Exhaustive studies have been made on interspecific competition under garden and field conditions by Stapledon, Davies, and Beddows [2] and Davies [3], whilst Chippindale [4] has thrown considerable light upon the problem by means of laboratory investigations. It was realized, therefore, that in order to obtain a herbage in which those species sown with rye-grass would be present in sufficient quantity for the purpose of the trial, the seeding of such species would have to be proportionately heavy. That the seedings of these species were heavy in relation to rye-grass (having in mind the differences in number of seeds per pound of the species) is shown by Table 1. Nevertheless the resulting figures for relative productivity of the species are not in proportion. A further examination of the data in Table 3 shows that the sown wild white clover in mixtures 10–18 was giving relatively greater quantities of 'keep' under hard-grazing conditions, with few exceptions, even in the period of one season's treatment. In mixtures 1–9, where small amounts of white clover had made a voluntary appearance, no such effect was apparent. The quantity of rough-stalked meadow-grass in the herbage was approximately similar under both systems of grazing,

TABLE 2. *The Blending of the Species and the Seedings in Pounds of Viable Seed per Acre of the Eighteen Mixtures*

Species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
Perennial rye-grass, Kentish	16	..	11	14	..	..	16	..	..	14	..	..	12	..	9	12	..	9
Timothy, indigenous	6	6	..	..	10	..	..	10	..	..	10	..	6	6	..	6	6	..
Cocksfoot, indigenous	..	14	11	..	..	14	..	..	16	..	..	14	..	12	9	..	12	9
Rough-stalked meadow-grass, commercial	..	..	..	7	7	7	..	..	..	6	6	6	4	4	4	4	4	4
Red clover, Montgomery	..	..	..	..	..	..	4	4	4	..	..	..	..	..	..	4	4	4
Wild white clover, Kentish indigenous	..	..	..	..	..	..	..	..	..	2	2	2	2	2	2	2	2	2

TABLE 3. *The Average Contribution of the Species to the Produce of Each of the Eighteen Mixtures under Light and Heavy Grazing. Productivity Marks on a Basis of 0–10*

Species	*Degree of grazing*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
Perennial rye-grass	Light grazing	8·2	..	7·8	7·9	..	..	7·1	..	..	6·6	..	..	5·4	..	6·0	5·5	..	4·9
	Heavy ,,	7·7	..	8·3	7·7	..	..	7·2	..	..	5·5	..	..	6·4	..	5·6	4·7	..	4·8
Timothy	Light ,,	1·3	4·8	..	..	6·7	..	..	6·1	..	..	3·4	..	0·6	2·5	..	0·6	2·4	..
	Heavy ,,	2·1	5·8	..	..	5·8	..	..	5·6	..	..	3·9	..	1·1	3·4	..	0·5	2·6	..
Cocksfoot	Light ,,	..	4·6	1·4	..	..	6·4	..	..	6·5	..	..	5·3	..	4·0	0·9	..	3·3	0·9
	Heavy ,,	..	4·0	1·7	..	..	6·2	..	..	5·2	..	..	3·0	..	1·6	0·3	..	1·8	0·3
Rough-stalked meadow-grass	Light ,,	..	..	..	1·8	3·3	3·5	..	..	..	1·4	2·5	2·3	1·1	1·6	1·1	0·9	0·9	0·9
	Heavy ,,	..	..	..	2·3	4·2	3·6	..	..	..	0·8	2·3	3·3	1·0	1·5	0·8	0·8	1·3	0·8
Red clover	Light ,,	..	..	..	..	..	..	2·9	3·8	3·4	..	..	..	..	..	..	1·5	1·9	1·5
	Heavy ,,	..	..	..	..	..	..	2·8	4·2	4·8	..	..	..	..	..	..	1·7	2·5	1·8
White clover*	Light ,,	0·5	0·6	0·8	0·3	T	0·1	T	0·1	0·1	2·0	4·1	2·4	2·9	1·9	2·0	1·5	1·5	1·8
	Heavy ,,	0·2	0·2	T†	T	T	0·2	T	0·2	T	3·7	3·8	3·7	1·5	3·5	3·3	2·3	1·8	2·3

* The wild white clover in mixtures 1–9 appeared voluntarily. † T = Trace.

although this species resembles wild white clover in its manner of growth and in its capacity to increase under conditions of close grazing. The indigenous timothy and the Montgomery red clover had, on the whole, contributed more to the keep in relation to the other species in the hard-grazed paddocks than in those lightly grazed, but the indigenous cocksfoot behaved in the opposite manner, the difference in mixtures 14 and 17 being very marked.

The data on relative palatability obtained from the mixtures plots are presented in Table 4.

TABLE 4. *Relative Amount of Herbage Offering and the Relative Amount Eaten from each of the Eighteen Mixtures under Light and Heavy Grazing*

Number of mixture	*The species in each mixture*	*Light grazing*		*Heavy grazing*	
		Amount offering	*Amount eaten*	*Amount offering*	*Amount eaten*
1	Perennial rye-grass, timothy	7·3	5·5	10·0	5·5
2	Cocksfoot, timothy	9·2	7·5	8·2	6·7
3	Perennial rye-grass, cocksfoot	7·1	5·7	10·0	5·8
4	Perennial rye-grass, rough-stalked meadow-grass	6·6	6·1	9·6	5·1
5	Timothy, rough-stalked meadow-grass	6·4	9·4	7·4	7·3
6	Cocksfoot, rough-stalked meadow-grass	5·6	7·5	9·6	6·3
7	Perennial rye-grass, red clover	7·5	6·2	10·0	5·8
8	Timothy, red clover	7·5	10·0	6·2	10·0
9	Cocksfoot, red clover	9·3	6·4	6·6	7·6
10	Perennial rye-grass, rough-stalked meadow-grass, white clover	9·4	6·6	8·1	7·9
11	Timothy, rough-stalked meadow-grass, white clover	6·1	9·1	6·5	9·7
12	Cocksfoot, rough-stalked meadow-grass, white clover	10·0	5·7	6·4	8·7
13	Perennial rye-grass, timothy, rough-stalked meadow-grass, white clover	8·7	5·7	8·2	8·0
14	Cocksfoot, timothy, rough-stalked meadow-grass, white clover	9·3	7·0	6·6	9·2
15	Perennial rye-grass, cocksfoot, rough-stalked meadow-grass, white clover	8·9	5·7	8·1	8·2
16	Rye-grass, timothy, rough-stalked meadow-grass, red and white clover	9·7	5·9	8·3	8·3
17	Cocksfoot, timothy, rough-stalked meadow-grass, red and white clover	9·9	7·5	7·7	8·8
18	Rye-grass, cocksfoot, rough-stalked meadow-grass, red and white clover	9·7	6·0	8·8	7·7

The mixtures may be conveniently studied in groups of three:

Mixtures 1, 2, and 3.—The botanical composition of the plots shown in Table 3 indicated mixtures 1 and 3 to be dominated by perennial rye-grass. Practically, therefore, these mixtures are a comparison between rye-grass with small amounts of other species and a mixture of timothy and cocksfoot—mixture 2. The relative amounts eaten in both light- and hard-grazed sections show the timothy and cocksfoot mixture to be the most palatable. The dominance of the rye-grass in mixtures 1 and 3 is reflected in the similar amounts offering and the amounts eaten of these two mixtures.

Mixtures 4, 5, and 6.—Rough-stalked meadow-grass was present in appreciable amount in each of the three mixtures. The relative amounts eaten in both sections have shown mixture 5 containing timothy to be the most palatable of the three, with the cocksfoot mixture next and the rye-grass mixture the least palatable. The proportion of rough-stalked

meadow-grass to timothy in mixture 5 is approximately the same as that of meadow-grass to cocksfoot in mixture 6, but the superior palatability of timothy has resulted in a greater amount of the timothy mixture being eaten, particularly under light-grazing conditions.

Mixtures 7, 8, and 9.—These mixtures consisted of one grass with red clover. The data show that mixture 8, consisting of timothy and red clover, was the hardest grazed plot in the trial under both systems of grazing. The rye-grass mixture and the cocksfoot mixture were of equal palatability under light grazing.

Mixtures 10, 11, and 12.—These mixtures were formed by adding white clover to the grasses composing mixtures 4, 5, and 6. Although this clover had made a voluntary appearance in these mixtures, it is doubtful whether the small amount contained in their herbage would have had any influence on the grazing. In view of the presence of large amounts of white clover in mixtures 10, 11, and 12, it is accordingly interesting to note that mixture 11, containing timothy, was the hardest grazed of the three plots in both sections, as it was in the mixture containing practically pure grass. Thus the inference is that the presence of wild white clover in quantity has not influenced the relative palatability of the plots when the clover is equally abundant in the plots compared.

Mixtures 13, 14, and 15.—These mixtures were composed of two top grasses, as in mixtures 1, 2, and 3, but with the addition of rough-stalked meadow-grass and white clover as bottom species. The highest degree of palatability was again given by mixture 14, containing timothy, as in mixture 2, whilst the relative palatability of the rye-grass and cocksfoot mixtures was similar. The behaviour of the cocksfoot in mixtures 14 and 15 as seen in Table 3 is interesting, for besides being suppressed by the rye-grass in mixture 15, it has evidently been suppressed by the white clover under hard-grazing conditions in mixture 14.

Mixtures 16, 17, and 18.—The effect of adding red clover to the species composing the previous group of three mixtures has not resulted in displacing the timothy-cocksfoot mixture, number 17, from the highest position of relative palatability for the group. It will be observed, however, that the margin is narrow under hard-grazing conditions. It is evident when comparing these data with those from mixtures 7, 8, and 9, in which group the blending of timothy and red clover gave such a palatable result, that the addition of other species has had a levelling effect upon the grazing. The suppressing effects upon the cocksfoot noted in mixtures 14 and 15 are again evident in mixtures 17 and 18.

Discussion

When the data from the single-species plots and the mixture plots are considered together, it is evident that in the present investigation timothy has proved to be the basis of palatability. In the single-species plots the two clovers were grazed harder than the timothy, although timothy was the hardest grazed of the grasses. The dominating effect of this species on palatability, however, is disclosed in the mixture plots, for the mixtures containing timothy were the hardest grazed plots throughout the trial whether under light- or hard-grazing conditions.

Moreover, in mixtures the effect of this species surpasses the effect of the clovers, for when red and white clover were equally abundant in the plots compared, the clover with timothy mixture exceeded the other mixtures in palatability.

It will be remembered that in the present trial, pure grass plots free from white clover were unobtainable. In the Penglais section of the experiment reported upon by Stapledon and Milton [5], however, the minute quantity of volunteer white clover present in the plots during the first harvest year was not sufficient of itself to cause any selective grazing. Timothy was the most palatable of seven grass species under these conditions. Davies [6] found timothy to be more palatable than numerous other grass species, whilst Beaumont, Stitt and Snell [7] and Kannenberg [8] accord it a high position. In the trials of Buerger and Radtke [9], however, the investigators found timothy to be highly palatable in relation to other species but attribute the fact to timothy having had the advantage of being in a younger stage of growth at the time of the trial.

The data concerning the pure plots of red and white clover show them to be very palatable as compared with the grasses. The good grazing of the Montgomery red clover is especially interesting, for it has been repeatedly observed in the seed-production fields of this species in Montgomeryshire that stock refuse to graze when turned into a field containing a practically pure stand of this clover. Considering the conditions of the present trial, however, it will be realized that there is a vast difference in offering to sheep a few plots of red clover situated among numerous grass plots, and in offering to them one 'plot' of pure red clover. Davies [6] found that clovers when regularly grazed are much sought after, and, further, that simple mixtures containing both clovers and grasses have a higher relative palatability than the individual grass species grown in pure plots.

In an investigation conducted by Stapledon and Milton [5], the data in respect to wild white clover showed it to be a highly palatable species. In discussing the qualities of wild white clover, however, Stapledon [10] mentions conditions under which this species may at certain periods be unpalatable.

Fenton [11] points out that the order of the palatability of species in mixed plots may differ from that in pure plots, as in mixed plots the species are subjected to various influences including that of competition. In the present investigation it was found that on the whole the sheep grazed each species in a mixture very uniformly, and that they were evidently influenced in their selection among the mixture plots by the palatability value of the dominant species. In consequence of this, the preference for one mixture was not due to the sheep selecting and closely grazing the most palatable species contained in it, but to their paying more attention to a mixture as a whole which contained either a dominant species or a blend of species which were palatable. It has been shown in a previous paper on this subject [1] that very definite selection took place among grasses and clovers in the prepared and permanent swards of ordinary farm fields. In such fields the herbage offering to the animal

consists of a reasonably uniform mixture of species. The present trial, however, consisted of a field containing a variety of mixtures, and the consequent behaviour of the animals was such that they chose their mixture from the variety rather than their species from the mixture.

Summary of Part I

Comparisons have been made of the relative palatability of simple seeds-mixtures in conjunction with single-species plots.

It has been shown that timothy formed the basis of the most palatable mixtures, although this species was not the hardest grazed among the pure plots.

There has been an indication that grazing becomes more uniform among contrasting mixtures in proportion to the addition of species to their composition.

Sheep on the mixture plots selected mixtures as such rather than individual species from mixtures.

The very high palatability of red clover, growing under conditions which allow the grazing animal an alternative diet, has been disclosed.

Part II. *Material and Methods*

The data obtained on the effect of manures on the palatability of upland pastures have been derived from plots used in conjunction with a controlled grazing and manuring experiment (E 117). This experiment was planned to supply supplementary evidence to two experiments, the results of which have been reported upon by Stapledon and Thomas [12] and Davies and Jones [13]. The data on palatability are dealt with in the present paper, but the main trial will be reported upon later.

In the trial here discussed four unfenced plots each of 1/100th acre were manured as follows:

1. Lime at the rate of 2 tons per acre of calcium carbonate.
2. Superphosphate at the rate of 4 cwt. per acre.
3. Superphosphate as above, with the addition of kainit and sulphate of ammonia at 4 cwt. and at 1 cwt. per acre respectively.
4. As plot 3, but with the addition of lime at the above rate.

For the sake of brevity, these plots will be referred to as Ca, P, PKN, and CaPKN. In addition, an area adjacent to the manurial plots was used as a control.

The first quantity of these manures was applied in the spring of 1930. The plots subsequently received each spring superphosphate, kainit, and sulphate of ammonia in similar quantities to the above. In addition, sulphate of ammonia at $\frac{1}{2}$ cwt. per acre was applied to the PKN and CaPKN plots at monthly intervals from the end of April to the end of September of each year.

These plots were laid down at two hill farms in North Cardiganshire. The pasture types investigated were:

1. An open-hill *Festuca-Agrostis* association.
2. An open-hill *Molinia* association.
3. An enclosed-hill *Festuca-Agrostis* association.

The first two pastures were at an exposed situation of approximately 900 feet elevation, the soils being a dry peat and a peat, respectively. These pastures will be referred to as Llety-*Festuca* and Llety-*Molinia*. The enclosed-hill pasture was at an elevation of 850 feet, but was situated in a much more sheltered position and on a light loam soil. This centre will be referred to as Bwlchrosser.

The method of collecting the data consisted in examining the plots at monthly intervals from April to October and giving marks on a scale of 0–10 for the relative degree to which they had been grazed, and recording the characteristics of the examination. Annual analyses of the swards were made to investigate any botanical changes.

Results

Data regarding the botanical composition of the herbage of the three pastures at the commencement of the trial and the composition of the herbage of the manurial and control plots after two years had elapsed are presented in Table 5.

These analyses are sufficient to show the trend and extent of the botanical changes under the influence of the manuring and grazing. A more detailed consideration of the botanical aspects of the situation will be undertaken when the experiment as a whole is reported upon.

The data in Table 5 show that Bwlchrosser was of a superior type to the other pastures, for besides being in a more sheltered position it was grazed by cattle as well as by sheep. This was the only pasture of the three which contained a legume. It will be noted that wild white clover increased in all plots at this centre by the second year except in PKN. At Llety-*Festuca* there was an increase of fine-leaved fescue and a consequent decrease of bent throughout the area as a whole. The most striking change, however, was at Llety-*Molinia*, where a marked decrease of *Molinia caerulea* and an increase of fine-leaved fescue occurred on the manured plots but especially on PKN and CaPKN. This alteration in the composition of a *Molinia* pasture when subjected to the influence of manures and defoliation has been discussed by Davies and Jones [13]. These investigators worked on fenced plots and used clippers as their defoliators. The fact that a similar result has been brought about by the combined effect of manures and uncontrolled grazing is an important point, and one which will be further dealt with in the results of the main trial.

Further study of Table 5 indicates that the composition of the control plots remained practically similar to the initial composition after the lapse of two years, and that the miscellaneous species made smaller percentage contribution to the herbage of the PKN and CaPKN plots of the Llety centres.

The data for the relative amounts eaten from the plots over the four years of the trial have been averaged for each season and are presented in Table 6.

The data show that the manures influenced the grazing even in 1930, the year of initial application. The manurial plots had a decidedly richer colour than the control, except the P plots. The effect of the manures as indicated by the selective grazing was more marked at the Llety centres

TABLE 5. *Percentage Contribution of the Species to the Herbage of Three Hill Pastures at the Commencement of the Investigation, and of the Individual Manurial Plots situated on these Pastures after Two Years of Treatment*

Pasture	*Treatment*	*Festuca ovina L. and rubra L.*	*Agrostis species*	*Molinia caerulea Moench.*	*Nardus stricta L.*	*Triodia decumbens Beauv.*	*Anthoxanthum odoratum L.*	*Holcus lanatus L.*	*Trifolium repens L.*	*Miscellaneous species*
Llety-*Festuca*	Initial composition	59	31	4½	..	Trace	..	..	..	5½
	Control	72	20½	Trace	..	..	Trace	..	..	7½
	CaPKN	89½	8½	..	..	½	..	..	..	1½
	PKN	94	5½	..	..	Trace	Trace	..	..	½
	Ca	71½	25	..	..	Trace	..	..	..	3½
	P	91½	4½	..	..	½	½	..	..	3
Llety-*Molinia*	Initial composition	10½	Trace	72½	10	..	..	..	..	7
	Control	11	Trace	83½	1	..	..	..	..	4½
	CaPKN	73½	1	25½	Trace	Trace	..	..	..	Trace
	PKN	60½	3	36½	..	..	..	..	..	Trace
	Ca	31½	½	65	2	..	..	..	..	1
	P	44	½	51½	1	1	..	..	..	2
Bwlchrosser	Initial composition	48½	46	..	..	½	½	..	Trace	4½
	Control	44½	47½	..	..	1	4	..	Trace	3
	CaPKN	48	32½	..	..	..	5½	7½	4	2½
	PKN	40½	53	..	..	..	4½	..	Trace	2
	Ca	28	56½	..	..	Trace	4½	5	4	2
	P	64	22½	..	..	½	2½	4½	1½	4½

Miscellaneous species: *Potentilla erecta* Hampe, *Galium saxatile* L., *Vaccinium Myrtillus* L., *Calluna* and *Erica* species, *Juncus squarrosus* L., *Luzula campestris* Br., *Scirpus caespitosa* L., and *Carex* species.

TABLE 6. *Relative Degree of Grazing on Unfenced Manurial Plots situated on Three Hill Pastures*

(Averaged relative markings with 10 as the most grazed plot)

Pasture	*Plot*	*Years of examination*			
		1930	*1931*	*1932*	*1933*
Llety-*Festuca* . .	Control	0·5	1·0	0·2	0·4
	CaPKN	8·5	10·0	10·0	10·0
	PKN	10·0	6·5	6·7	9·3
	Ca	1·5	3·7	2·0	2·0
	P	2·0	1·2	0·2	0·7
Llety-*Molinia* . .	Control	0·3	10·0	1·0	0·3
	CaPKN	9·5	5·2	10·0	10·0
	PKN	10·0	5·2	9·0	9·6
	Ca	0·7	8·3	1·0	2·3
	P	0·7	6·6	1·0	1·1
Bwlchrosser . .	Control	4·5	2·2	2·8	2·7
	CaPKN	10·0	10·0	10·0	10·0
	PKN	8·5	4·5	5·0	7·9
	Ca	6·0	7·5	7·1	8·9
	P	7·0	2·7	4·6	5·7

than at Bwlchrosser. Taking the data as a whole, the CaPKN plot was, with very few exceptions, the hardest grazed plot on each pasture over the period of the trial. The relative degrees of grazing on the Llety-*Molinia* pasture during 1931 call for explanation. The mass of dead material on the plots was fired early in April of that year. The result of this action was that when the new growth of *Molinia* appeared it was everywhere palatable to the sheep, and thus no differential grazing occurred. Later in the season, however, the *Molinia* on the PKN and CaPKN plots made such luxuriant growth that it quickly became unpalatable. In consequence of this, these plots were less heavily grazed than the others. The CaPKN plot was continually hard grazed at Bwlchrosser. The sole of this sward was always laid bare, but although the CaPKN plot at Llety-*Festuca* was the hardest grazed of that group there always remained a spongy basal growth. As mentioned above, cattle as well as sheep grazed the Bwlchrosser pasture and it was observed that the cattle paid marked attention to the plots. Heddle and Ogg [14] have emphasized the importance of cattle grazing on hill pastures.

The Ca plot was better grazed than the PKN plot at Bwlchrosser after the first year. Reference to Table 5 shows that wild white clover had made an appreciable increase on the Ca plot by 1932, whereas only a trace was to be found on PKN. It is probable, therefore, that the presence of white clover partly accounted for the superior grazing of the Ca plot. A critical examination of the plots over the four years of the trial, however, points to the fact that calcium affected the grazing in a direct way, and not only through the medium of botanical composition. The superior way in which CaPKN was grazed compared with PKN at the Llety-*Festuca* centre from 1931 onwards is a case in point, for on that pasture not only was white clover entirely absent from the herbage, but the botanical composition of the CaPKN and PKN plots was almost identical.

Comparing the relative degrees of grazing of the Ca and P plots, it will be noted that the Ca plots were, on the whole, the better grazed plots at every centre. The effect on the grazing of Ca alone and P alone at the Llety-*Molinia* centre was extremely slight.

Discussion

One of the most interesting disclosures of the trial is that stock repeatedly sought out these small manured plots situated in the huge acreage of open-hill grazing land. The Bwlchrosser pasture was not in the same category as the Llety-pastures in this respect, but even here the plots were on a pasture of over ten acres.

In the interpretation of the results of differential grazing among the plots two main factors are discernible. The first of these is the botanical change due to the grazing animal and the increased fertility due to manuring. The second is the evident effect of the fertilizers increasing their respective ingredients in the chemical composition of the plants. There is evidence that these two factors have acted together at the Llety-*Molinia* centre. It has been shown that in the course of the trial the *Molinia* was largely replaced by fine-leaved fescue. In all probability the initial step was the increased palatability of the *Molinia* on account of the direct action of the fertilizers on its chemical composition, particularly on the CaPKN and PKN plots. Previous work and the results of another section of the present experiment have shown that *Molinia* cannot stand continuous or even rotational grazing for very long, but largely dies out, thus enabling other species to take its place. In this instance fine-leaved fescue, and to a lesser extent *Agrostis* species, have done this, and these species have been encouraged by the increased fertility consequent upon manuring. The directly chemical factor was evidently the major one on the other two pastures, although a certain amount of botanical change has been noted.

Chemical analyses were not carried out in connexion with the present trial, but it has been shown by Orr [15] that the change in composition of the soil due to fertilizers increases the mineral-content of the pasture, and further, that the increase is most marked on poor soils. Fagan and Provan [16], working in conjunction with Stapledon and Thomas [12], found a similar result, whilst Beaumont [17] in interpreting the results of a palatability experiment with manures considered that the higher content of nutrients in the vegetation of the limed and fertilized plots accounted for their greater palatability. This applied particularly to lime and nitrogenous manures.

The investigation of Heddle and Ogg [14] has a direct bearing upon the present experiment. The 'short dry grass' type of pasture described by these investigators is apparently very similar to the Llety-*Festuca* pasture under discussion. It is noteworthy that the results from lime and phosphatic manuring are not dissimilar in the two experiments. These investigators, moreover, draw attention to the evidence given by Stapledon [18] to the effect that the supply of available nitrogen may be a controlling factor in the improvement of hill pastures. Although there was no plot in the present series receiving nitrogen alone, it has

been observed in the hill work of the Station that nitrogen has repeatedly a striking effect upon herbage, and in all probability it was this ingredient more than any other which brought about the high palatability of the CaPKN and PKN plots. The presence of kainit in the combination, however, may have had a considerable effect upon the palatability results, for not only did Heddle and Ogg find that potash manuring improved the palatability of the hill pastures, though its effect was temporary, but Elofson [19] found that by adding potash salts to part of a sward having had lime, superphosphate and natural manure over its entire area, the palatability of the herbage was greatly increased. Schneider-Kleeberg [20] also cites the beneficial effect upon palatability of potash salts. The evidence in respect of the present trial, however, is specially significant in the light of the data of Fagan and Watkins [21]. Chemical analysis conducted by these investigators upon herbage derived from plots adjacent to the Llety-*Festuca* plots of the present trial showed that kainit not only increased the potash-content of the herbage, but that the chlorides of the kainit had a very striking effect upon the chloride-content of the herbage. Whatever the individual effect of the fertilizers may have been on the herbage of the three pastures here discussed, the net result of this combination as CaPKN or PKN has been the elimination of two factors which Heddle and Ogg found to deter the action of manures on hill pastures, namely, that of uncontrolled grazing and the absence of superior species in the herbage.

The vigour of the grass growth and the consequent discouragement of the miscellaneous species under nitrogenous manuring on the Llety pastures is interesting in view of the results obtained by Woodman and Underwood [22] working on a good permanent pasture.

Summary of Part II

The effect of artificial fertilizers and lime upon the palatability of hill pastures has been investigated.

The action of two main factors has been disclosed, that of the direct effect of the fertilizers upon the nutrients of the plant, and that of botanical change. The second of these factors is dependent upon the first in conjunction with the grazing animal.

It has been shown that manures with uncontrolled grazing can effect a marked improvement in all three types of hill pastures investigated, but especially in a *Molinia* pasture.

The beneficial result of firing a *Molinia* pasture in early spring has been indicated.

Complete manuring, including lime, has given the best results in terms of relative palatability.

The effect of lime, either alone or in combination with the fertilizers, has been evident and much more marked than that of superphosphate.

The relationship of the results obtained to the chemical considerations has been discussed at length.

Finally, the use of a combination of phosphatic, potassic, and nitrogenous manures, again with the addition of lime, has resulted in the removal of major factors which hinder hill improvement.

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FERTILIZERS AND THE EMPIRE

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THE British Empire is not rich in the raw materials required for the manufacture of fertilizers, but this observation applies more particularly to phosphoric acid and potash, seeing that nitrogen is now very largely derived from the atmosphere. But even in regard to atmospheric nitrogen the means of fixing it in a form in which it can be employed by agriculture call for the provision of certain raw materials of which the two most important are coal and sulphur: coal for providing hydrogen, and sulphur for the manufacture of sulphuric acid. It should, however, be noted that in Great Britain the sulphate radical for synthetic sulphate of ammonia is provided by anhydrite. In coal the Empire is very rich, but in regard to sulphur it is not nearly so well supplied.

Sulphur.—Some attention must be given to sulphur because this important substance is necessary, not only for the manufacture of sulphate of ammonia, the most important of nitrogenous fertilizers, but also for that of superphosphate. A detailed analysis of the position of the Empire in connexion with sulphur will be found in the reports[1] of the Imperial Mineral Resources Bureau, now merged in the Imperial Institute.

Great Britain is, in the main, dependent upon Spanish and Norwegian pyrites for most of the sulphur required in the manufacture of superphosphate and by-product sulphate of ammonia. There is, however, an annual home production of about 110,000 to 125,000 tons of sulphur in the form of spent oxide as a by-product in the purification of coal gas. As mentioned above, combined sulphur is used in large quantities as anhydrite for fixing atmospheric nitrogen as sulphate of ammonia. Elementary sulphur is imported from the U.S.A. and Italy, largely for making arsenic-free sulphuric acid.

South Africa imports sulphur from Italy and pyrites from Spain. The home-production of pyrites is not used for fertilizer manufacture, although there is a possibility that it may be in the near future.

India buys sulphur from Italy and Japan.

Cyprus is an important producer of pyrites, her annual output being about 250,000 tons.

Australia has a most important native source of sulphur in her lead and zinc ores, but in the main she is dependent upon the United States for her supplies of this substance.

New Zealand also obtains her sulphur from the United States, although from time to time certain quantities have been obtained from Japan. There is also a small annual home-production of about 1,000 tons.

Newfoundland possesses abundant deposits of pyrites associated with copper ore, but up to the present they have not been worked to any great extent.

Phosphate rock.—The world consumes about 68 per cent. of its

[1] Cf. *Sulphur and Iron Pyrites*, published by H.M. Stationery Office, 1922, price 1*s.* 6*d.* net.

phosphoric-acid requirements in the form of superphosphate, which is made by treating mineral phosphate rock with sulphuric acid. Unfortunately, phosphate rock is relatively no more abundant in the Empire than is sulphur, Christmas and Ocean and Nauru Islands in the Pacific being the only important British sources of supply. These islands shipped a total quantity of about 712,000 tons of phosphate rock in 1932, out of a world production of 7,037,988 metric tons. French North Africa and the United States between them supply 84 per cent. of the world's phosphate-rock requirements.

The Empire production figures for the 4 years 1929–32 are given hereunder:

TABLE 1. *Empire Production of Phosphate Rock*

(*metric tons*)

Country	*1929*	*1930*	*1931*	*1932*
South Africa	..	..	1,906	1,183
Canada	1,075	37	..	1,194
British India	22	303	111	123
Australia	71	26	619	883
Christmas Island	122,428*	124,544*	66,528*	87,376*
Ocean and Nauru Islands	561,680*	450,393*	381,620*	624,895*

* Exports.

Ocean and Nauru Islands are under the control of the British Phosphate Commissioners and the deposits are the property of the Governments of Great Britain, Australia, and New Zealand, the respective shares of each country being 42, 42, and 16 per cent. Practically the whole of the annual production is absorbed by Australia and New Zealand for the manufacture of superphosphate.

Production in Christmas Island is in the hands of a commercial organization, and nearly the whole of the output is now being sold in Japan.

Great Britain obtains the major portion of her phosphate rock from North Africa (Tunis, Algeria, and Morocco). Canada purchases her requirements from the United States (Florida and Montana). South Africa is supplied from Morocco. The requirements of other Empire territories are not very large. India and Ceylon absorb about 10,000 tons of phosphate rock in ground form from Egypt, but this is used for direct application to the land as a fertilizer.

There are very extensive deposits of phosphate rock (apatite) in Canada, but they are not specially suitable for the manufacture of superphosphate in their natural form and are being worked only to a very limited extent. In the period 1878 to 1892 Canada was a considerable producer of phosphate rock, the maximum output being 30,866 metric tons, attained in 1890. The success which has attended the conversion into 'concentrate' of the Russian apatite, mined in the Kola peninsula (achieved by a flotation process with a material similar to that found in Canada), may at some future time enable the Canadian apatite deposits to be mined with a prospect of success.

There are several deposits of phosphate rock in the Empire which at present are dormant or are only being worked to supply a local demand. One such is in county Clare, Irish Free State; another is located at Saldanha Bay, South Africa, whilst others are found in Nigeria, India, Australia, New Zealand, and Palestine.

Guano.—Natural guano, of which the world produces about 170,000 tons annually in normal times, is produced in British India (exports, 5,471 tons in 1931), Seychelles Islands (exports, 4,731 tons in 1931), and South Africa (production, 7,140 tons in 1931): Peru and the islands off the South American coast are the principal sources of supply.

Empire Production and Consumption of Fertilizers

The history of the commercial production of fertilizers in Great Britain goes back nearly one hundred years, and to the mother country belongs the honour of being the pioneer of fertilizer manufacture and use. It is clear that superphosphate was the first chemical fertilizer produced and the statistical history of the industry has been epitomized in *Phosphates and Superphosphates.*[1] The manufacture of superphosphate was commenced in Great Britain by Sir (then Mr.) John Bennet Lawes in 1842, but it was not until about 1900 that this fertilizer was made in Australia; South Africa commenced superphosphate production in 1913, whilst in Canada there is no evidence of production on a substantial scale prior to 1929.

Nitrogenous fertilizers.—Prior to the War, 1914–19, the two most important sources of supply were by-product sulphate of ammonia and nitrate of soda.

Australia was apparently a producer of sulphate of ammonia prior to 1908, but no statistics are available for preceding years. In the case of Canada statistics of sulphate of ammonia production are available from 1913 onwards, though it is clear that she had a substantial output for many years prior to the War. The production of sulphate of ammonia in India commenced in 1909.[2] Table No. 2 has been prepared from the available statistics.

In this table the production of such compounds as phosphate of ammonia, &c., is included for Great Britain in 1909, but for the succeeding years the statistics refer to sulphate of ammonia only. According to the Statistical Summary of Mineral Industry of the British Empire, published annually by the Imperial Institute, Canada produced 3,700 metric tons of phosphate of ammonia in 1931: in addition Canada has been an important producer of calcium cyanamide for many years.

The Statistical Summary of the Imperial Institute gives the following figures relating to the Canadian production of calcium cyanamide (metric tons): 1927, 80,264; 1928, 77,216; 1929, 228,604; and 1930, 150,147.

The only other important production of nitrogen in the Empire is that of nitrate of potash, of which India has a varying annual output. This

[1] *Phosphates and Superphosphates*, by A. N. Gray. London: The International Superphosphate Manufacturers' Association.

[2] *India's Resources in Mineral Fertilizers*, by Sir E. Pascoe. Bulletin No. 42 of Indian Industries and Labour.

TABLE 2. *Production of Sulphate of Ammonia in Empire Countries*

(*metric tons* × 1,000)

	Great Britain and Ireland (1*a*)	*Australia* (1)	*Canada*	*India* (2)	*S. Africa* (3)
1909	354·7 (4)	3·5	..	..	..
1913	370·8	5·5	9·6	..	..
1919	356·7	12·9	10·7	4·5	..
1920	376·1	11·9	18·1	3·8	..
1928	573·2	11·3 (5)	25·5	15·7	1·0
1929	853·8	21·8 (3)	31·0	17·9 (3)	1·0
1930	689·3	9·0 (3)	21·7	16·4 (3)	0·2
1931	533·0	11·2 (3)	25·7	12·3 (3)	0·6

(1*a*) The figures for 1913–31, referring to sulphate of ammonia only, are from the British Sulphate of Ammonia Federation Report, 1931–2.
(1) The figures for the period 1928–31 are for the fertilizer year ending June 30 of the year shown.
(2) Indian Industries and Labour, Bull. No. 42, previously cited.
(3) Statistical Summary, 'Mineral Industry of British Empire, &c.', Imperial Institute.
(4) Total production of ammonia products, expressed as sulphate of ammonia equivalent (Brit. Sulph. Amm. Rept. 1931–2).
(5) Exclusive of Victoria and Queensland.

salt is exported to Great Britain, Ceylon, China, United States, Mauritius, and other destinations, only a very small quantity being used in India itself.

The statistics of production are given hereunder, but owing to the withdrawal of restrictions on the manufacture of saline substances in India in 1924, production figures subsequent to that year are estimates:

TABLE 3. *Production of Nitrate of Potash in India*[1]

(*metric tons*)

1919	20,030
1920	17,154
1928	4,800
1929	5,000
1930	4,700
1931	6,600

Phosphate fertilizers.—In connexion with the Empire production of phosphoric acid the principal fertilizer to consider is superphosphate. Table 4 gives the Empire production; the figures are, in the main, taken from *Phosphates and Superphosphates*, previously cited.

The second phosphoric-acid fertilizer in order of tonnage is basic slag, but as it is a by-product from steel manufacture very few statistics are available. Among Empire countries the Union of South Africa, Canada, India, and Australia are producers of steel, but only in regard to Canada are any statistics of basic-slag production to be found in the *International*

[1] Statistics for 1919–20 for *India's Resources in Mineral Fertilizers*, Bull. No. 42, 1928–31, from the Statistical Summary of the Mineral Industry of the British Empire, &c., Imperial Institute.

TABLE 4. *Empire Production of Superphosphate*

(*metric tons* × 1,000)

	Great Britain and Ireland	*Australia* (1)	*Canada*	*New Zealand*	*South Africa*
1911	766·5	156·5	..	..	..
1913	823·2	275·0	..	..	1·0 (2)
1919	678·4	130·6	9·0	21·1	10·0 (3)
1928	506·8	731·5	4·7	274·0	87·1
1929	606·9	913·9	30·5 (2)	289·6 (5)	89·8
1930	568·8	828·0 (4)	64·0 (2)	252·0 (5)	88·0
1931	475·7	670·7 (4)	57·6 (4)	219·5 (5)	70·5
1932	532·1	594·3 (4)	46·7 (4)	304·8 (5)	64·0

(1) From 1911 to 1919 estimated on basis of imports of phosphate rock.
(2) Estimated.
(3) Estimated on the basis of phosphate-rock imports.
(4) Year ending June 30.
(5) Years ending March 31 of succeeding year.

Year Book of Agricultural Statistics (Rome), and even these are not regularly published. The figures given are:

TABLE 5. *Production of Basic Slag in Canada*

(*metric tons*)

1922	8,330
1923	5,135
1924	3,251
1925	2,024
1926	4,393
1927	2,176

The Empire does a very considerable trade in bones and bone-products, but having regard to the nature of the fertilizer no production statistics are available. It may, however, be noted here that India exports from 50,000 to 75,000 tons of raw bone annually, and, in addition, sends out each year from 35,000 to 40,000 tons of bonemeal and similar materials. Canada, on balance, is an exporter of raw bones and an importer of about 2,000 tons of treated bone-products annually. Australia exports a small quantity of bones and bone-products yearly, whilst New Zealand is an importer on balance. South Africa exports small quantities of raw bones and imports from 2,000 to 8,000 tons of bone-products each year.

The only potentially important Empire source of potash is Palestine, where for the past two or three years the waters of the Dead Sea have been evaporated for the production of potash, bromine, &c. Up to the end of 1932 the exports of potash were small, but it is thought that in the very near future, with the anticipated increase in production, the exports will speedily grow in importance.

The import and export statistics may now be examined in order that an attempt may be made to establish the approximate consumption of plant-foods in the Empire countries.

Imports, Exports, and Consumption of Fertilizers: Great Britain and Ireland

For Great Britain and Ireland as a whole, consumption figures for the seven years 1926–32 have been worked out by the International Superphosphate Manufacturers' Association, in terms of pure plant-food, as follows:

TABLE 6. *Plant-food Consumption in Great Britain and Ireland*

(*metric tons*)

	N	P_2O_5	K_2O
1926	44,150 (1)	162,219	47,500
1927	42,350 (2)	165,235	54,921
1928	43,150 (2)	166,770	51,203
1929	49,850 (2)	212,546	61,388
1930	49,644 (2)	193,459	49,659
1931	45,950 (2)	157,113	52,500
1932	58,200 (2)	142,008	41,100

(1) Year ending May 31. (2) Years ending June 30.

The table may be taken as reliable as it has been prepared from information obtained from the respective industries and in the majority of cases is based upon the actual sales of the respective products. It has been thought more convenient for reference purposes to give the statistics of the three elements of plant-food in the one table and in complete form, but in regard to the Dominions it is necessary to examine the statistics of imports and exports of each plant-food in turn in order that something in the nature of an estimate of consumption may be attempted. It will be desirable to take each of the Dominions separately for this purpose, commencing with Australia.

Australia

For the years 1924–8 Australia was an exporter of sulphate of ammonia to the extent of about 4,000 tons per annum, but since 1929 she has consumed her entire production and in addition has imported an average of 7,000 tons per year. The import of nitrate of soda, which was 10,345 metric tons in 1924, had fallen to only 160 tons in 1931. The statistics make it evident that superphosphate is the only fertilizer for which there is a large demand in Australia, but this is only what might be expected having regard to the fact that the soils of the Commonwealth are very poor in phosphoric acid and consequently a dressing of superphosphate results in remarkable increases in crops. The annual demand for superphosphate, after a setback which occurred in 1930, 1931, and 1932, is again approaching one million tons, practically the whole of which is made in Australia from high-grade phosphates derived from Ocean and Nauru Islands. The superphosphate is therefore of high grade (about 20·5 per cent. P_2O_5), hence the equivalent annual consumption of phosphoric acid for the seven years 1925–31 varied between 142,475 tons (1931) and 187,359 tons (1929).

TABLE 7. *Net Imports* (1) *of Phosphatic and Potassic Fertilizers into Australia* (2)

(*metric tons*)

	Superphosphate	*Bones, &c.*	*Guano*	*Nitrate of potash*	*Other potash salts*
1924	77	−2,635 (3)	41,756 (4)	.. (5)	.. (5)
1925	306	−2,528 (3)	14,803	365	.. (5)
1926	39	−1,252 (3)	2,115	571	.. (5)
1927	86	− 699 (3)	1,083	660	.. (5)
1928	55	− 633 (3)	2,643	459	4,850
1929	420	−1,056 (3)	127	714	5,826
1930	13	− 584 (3)	nil	1,058	6,292
1931	−15 (3)	− 549 (3)	nil	488	4,599

(1) Imports, less exports or re-exports.
(2) *International Year Book of Agricultural Statistics.*
(3) Exports exceed imports.
(4) Year ending June 30.
(5) Figures not available.

The Australian consumption of other fertilizers is obviously relatively small. The figures of net imports of potash given in Table 7 show that the demand for potash fertilizers does not exceed from 5,000 to 7,000 tons per annum or, say, from 1,500 to 2,000 tons of pure potash. The consumption of nitrogenous fertilizers in the same period may be calculated as follows:

TABLE 8. *Estimated Consumption of Nitrogenous Fertilizers in Australia*

(*metric tons*)

	Sulphate of ammonia			*Nitrate of soda*	*Other nitrogenous fertilizers*
	Production	± *Net imports*	= *Consumption*		*Net imports*
1925	(1) 14,932	− 4,560	10,372	4,452	139
1926	(1) 17,248	− 5,825	11,423	11,294	188
1927	(1) 10,916	− 4,669	6,247	9,437	129
1928	(2) 11,342	− 1,944	9,398	8,251	504
1929	(2) 21,806	+ 5,706	27,512	8,412	212
1930	(2) 9,027	+12,780	21,807	6,008	293
1931	(2) 11,179	+ 3,016	14,195	160	168

(1) See note 5 to Table 2.
(2) Years ending June 30.

In 1929, therefore, the apparent consumption of nitrogenous fertilizers attained about 36,000 tons, but the world crisis had reduced the demand to 14,500 tons in 1931. It is understood, however, that the above figures, which take no account of stock variations, do not represent the actual position as to nitrogen consumption which is understood to have represented 7,000 metric tons of pure nitrogen in 1929 and 5,200 tons in 1931–2.

Canada

TABLE 9. *Imports of Nitrogenous Fertilizers into Canada* (1)

(*metric tons*)

	Sulphate of ammonia	*Nitrate of soda*	*Other nitrogenous fertilizers* (2)
1924 . .	−11,493 (3)	19,492	− 59,000
1925 . .	−11,033 (3)	20,085	− 79,000
1926 . .	−12,777 (3)	26,188	− 73,000
1927 . .	−12,489 (3)	24,207	− 98,000
1928 . .	− 9,183 (3)	24,295	−121,140
1929 . .	−20,653 (3)	30,733	−172,640
1930 . .	− 7,791 (3)	28,857	−137,041
1931 . .	+ 6,534	13,834	− 46,106

(1) *International Year Book of Agricultural Statistics.*
(2) Exports of calcium cyanamide, less imports of nitrate of ammonia.
(3) Exports exceeding imports.

TABLE 10. *Imports* (1) *of Phosphatic and Potassic Fertilizers into Canada* (2)

(*metric tons*)

	Super-phosphate	*Basic slag*	*Bones, &c.*	*Guano*	*Potassic fertilizers*
1924	37,488	.. (3)	+ 205	945 (4)	7,847
1925	56,632	6,070	− 97	..	12,933
1926	69,779	5,190	+ 729	..	14,240
1927	78,552	5,871	+ 71	..	18,033
1928	88,441	12,683	+ 1,213	..	23,183
1929	88,836	12,361	+ 1,578	..	17,432
1930	116,020	8,669	+ 2,698	..	35,826
1931	88,948	11,740	+ 1,925	..	32,810

(1) Imports less re-exports.
(2) *International Year Book of Agricultural Statistics.*
(3) Figures not available.
(4) No statistics available for years subsequent to 1924.

The principal trade in fertilizers in Canada is in compounds or mixtures containing two or more of plant-foods. Until quite recently the phosphoric acid required was nearly all imported, the United States being the main source of supply. The trade in mixed fertilizers follows very much the same lines as in the United States, there being a long list of mixtures, with varying analyses, the fertilizers being sold on the basis of the guaranteed plant-food contents, such, for example, as 4. 8. 4, which means that the fertilizer contains 4 per cent. by weight of nitrogen, 8 per cent. phosphoric acid, and 4 per cent. potash. The Dominion authorities now publish detailed annual statistics of fertilizer consumption, the most recent statement available[1] referring to the fertilizer year

[1] *Canada—Monthly Bulletin of Agricultural Statistics*, vol. 25, No. 287, July 1932. Since this paper was written the figures for 1932 have been published in the *Monthly Bulletin* for June 1933.

ended June 30, 1931. Five statistical tables are given, the first being a comparative table relating to sales of fertilizer materials and mixed fertilizers in the years ending June 30, 1930 and 1931 respectively. The second table gives details of Canadian production, imports, and exports, and is reproduced hereunder, the figures having been converted to metric tons:

TABLE 11. *Production, Imports, and Exports of Fertilizers in Canada as reported by Manufacturers and Importers during the year July 1, 1930 to June 30, 1931*

(*metric tons*)

	Production	*Imports*	*Exports*
Mixed fertilizers	106,238	17,390	7,024
Sulphate of ammonia	19,038	5,073	6,436
Cyanamid	44,493	605	55,873
Calcium nitrate	..	102	5
Nitrate of soda	..	11,341	151
Superphosphate	26,791	97,075	815
Basic slag	..	9,642	..
Nitro-chalk	..	762	..
Bone phosphate	..	907	..
Phosphate rock	..	17,514	..
Bonemeal	555	287	..
Bone flour	..	14	..
Muriate of potash	..	21,176	37
Sulphate of potash	..	1,999	..
Potash salts and kainit	..	2,366	..
Tankage	2,381	9,174	824
Sheep manure	..	383	..
Dried blood	282	..	144
Whale products	63	..	..
Fish meal	227	44	..
Other materials	984	931	26
Total	201,052	196,788	71,335

The third table of the Canadian publication gives the sales of fertilizers, except for manufacturing purposes, during the year ended June 30, 1931, and shows the quantity of each product sold for agricultural consumption in each of the provinces into which the Dominion is divided. Ontario is by far the largest consumer among the Canadian provinces, whilst the so-called Prairie provinces (Manitoba, Saskatchewan, and Alberta) together used only 1,611 metric tons out of a total Canadian consumption of 257,842 metric tons. The next table gives the percentage analysis of the mixed fertilizers sold during the year, and it is interesting to note that 58 different mixtures are given, with ratios of N, P_2O_5 and K_2O, varying from 0 : 2 : 10 to 15 : 30 : 15. The details enable the quantity of the plant-foods sold in mixed fertilizers to be calculated and these are given in a final table, as follows:

Year ending	*N*	*P_2O_5*	*K_2O*
30. 6. 1931	4,610 m. tons	12,591 m. tons	10,298 m. tons
30. 6. 1930	4,429 ,,	13,301 ,,	9,907 ,,

The Dominion Department of Agriculture is certainly to be congratulated on the very full and detailed statistics of fertilizer consumption which it produces.

New Zealand

There are no statistics published as to production of nitrogenous fertilizers in New Zealand, and it is therefore to be assumed that if any sulphate of ammonia is manufactured at gas works the total quantity would be small. The import statistics are given below:

TABLE 12. *Imports of Nitrogenous Fertilizers into New Zealand*

(*metric tons*)

	Sulphate of ammonia (1)	*Nitrate of soda* (1)	*Nitrate of potash* (2)	*Other nitrogenous fertilizers* (2)
1925	982	1,345	..	..
1926	1,236	1,145	..	..
1927	838	2,400	62	..
1928	2,155	869	97	..
1929	9,136	2,132	88	48
1930	8,377	1,884	65	51
1931	4,923	681	78	36

(1) *International Year Book of Agricultural Statistics.*
(2) *The Mineral Industry of the British Empire*, Statistical Summary.

There is no record of exports or re-exports, hence it may be assumed that the imports equal consumption. It is of interest to note the substantial increase in imports of nitrogenous fertilizers from 1929 onwards, which would seem to suggest that agriculture in the Dominion is giving increasing attention to this important plant-food.

In regard to phosphatic fertilizers New Zealand, like Australia, is dependent upon its own manufacturing resources for superphosphate, which is made from Ocean and Nauru phosphates supplemented by occasional supplies from other sources. The details of imports of phosphatic fertilizers are appended:

TABLE 13. *Imports of Phosphatic Fertilizers into New Zealand* (1)

(*metric tons*)

	Superphosphate	*Basic slag*	*Bones, &c.*	*Guano*
1925	+ 79	47,281	2,742	10,964
1926	− 614 (2)	47,278	1,722	19,588
1927	+6,203	39,252	955	21,569
1928	+ 520	93,010	487	24,065
1929	+ 1	96,014	1,189	29,722
1930	− 991 (2)	62,787	1,036	10,670
1931	− 573 (2)	71,451	163	17,345

(1) *International Year Book of Agricultural Statistics.*
(2) Surplus of exports.

When it is remembered that New Zealand manufactured a large quantity of superphosphate (the figures of production will be found in

Table 4), it will be evident that the consumption of phosphoric acid in the Dominion is very considerable. If it be assumed that the superphosphate consumed contains 20·5 per cent. phosphoric acid; that basic slag averages 17 per cent.; that the bone fertilizers are, say, 30 per cent. average, and guano 13 per cent., the following estimate of consumption may be framed:

TABLE 14. *Consumption of Phosphoric Acid in New Zealand*

(*metric tons*)

	As superphosphate	*Basic slag*	*Bones, &c.*	*Guano*	*Total*
1925	26,698	8,038	823	1,425	36,984
1926	31,050	8,037	517	2,546	52,150
1927	43,736	6,533	287	2,814	53,370
1928	56,256	15,812	146	3,128	75,342
1929	59,360	16,322	357	3,864	79,903
1930	51,448	10,674	311	1,387	63,820
1931	45,395	12,147	49	2,255	59,846

The increase in consumption of phosphoric acid from 1925 to 1929 is remarkable, and even the world crisis, although it has caused a setback, has not resulted in such a severe decrease as might have been expected.

Until the year 1931 rather more potash was consumed in New Zealand than in Australia, as a comparison of the subjoined figures with those in Table 7 will show:

TABLE 15. *Imports of Potassic Fertilizers into New Zealand* (1)

(*metric tons*)

1925	9,137
1926	11,518
1927	6,463
1928	12,664
1929	9,277
1930	8,774
1931	4,749

(1) *International Year Book of Agricultural Statistics.*

South Africa

The soils of the Union of South Africa are poor in phosphoric acid over large areas, and it therefore follows that, just as in Australia and New Zealand, the consumption of phosphoric acid is very much larger than that of the other plant-food elements, nitrogen and potash.

The Union is a member of the International Superphosphate Manufacturers' Association, and as this body has made a very careful calculation of the consumption of the plant-foods in all its member countries it is possible, as in the case of Great Britain, to give in the form of a summary table the figures for the period 1926–31 for nitrogen, phosphoric acid, and potash.

TABLE 16. *Consumption of Plant-foods in the Union of South Africa*

(*metric tons*)

	Nitrogen	*Phosphoric acid*	*Potash*
1926	627	19,601	740
1927	253	24,146	1,100
1928	1,054	32,353	1,450
1929	831	35,090	1,250
1930	540	30,549	1,050
1931	575	24,962	450

It may be of interest, however, to give some details of the form in which the plant-foods are supplied. Thus nitrogen is employed in the form of either nitrate of soda or sulphate of ammonia: in 1926, 521 tons of nitrogen were in the form of nitrate of soda and only 106 tons in the form of sulphate of ammonia. In subsequent years the proportion of nitrate of soda has fallen to very small dimensions; in 1930 only 22 tons were used as nitrate of soda and 518 tons as sulphate of ammonia.

Phosphoric acid is applied mainly in the form of superphosphate, about 50 per cent. being manufactured in the Union and 50 per cent. imported from Great Britain, Holland, and other European countries. In 1931, 23,549 tons of phosphoric acid were consumed as superphosphate and 1,413 tons of phosphoric acid as basic slag.

It would be impossible in the present brief survey to give details of the fertilizer trade and consumption of all the territories of the Empire, even were all the necessary statistics available, but it is proposed before concluding to refer specifically to the position in India and Ceylon.

India and Ceylon

Despite its teeming population India is a very small consumer of fertilizers, indeed in many respects the great sub-continent is more important as an exporter of raw materials than as a manufacturer or importer of fertilizers. As has been mentioned previously, India annually exports important quantities of bones and bone-products, but she also produces and exports nitrate of potash and sulphate of ammonia. In his monograph on India's Resources in Mineral Fertilizers, Bulletin No. 42 of Indian Industries and Labour, to which reference has been made previously, Sir Edwin Pascoe refers to the export of bones as 'a regrettable feature in the economic status of India'; but it is by no means a unique feature, for although the production of sulphate of ammonia reached only about 15,000 tons to 20,000 tons annually up to 1927, from 6,000 to 8,500 tons were exported. Since that date, however, there has been a marked change as India has become on balance an importing country. Table No. 17 gives the details from 1925 to 1931.

Ceylon is a market of growing importance for fertilizers, as the published statistics show.

So far as is known, there is no manufacture of fertilizer materials in the island, hence the imports may be assumed to represent the consump-

TABLE 17. *Indian Trade in Sulphate of Ammonia*

(*metric tons*)

	Imports	*Exports*
1925 . .	1,150	8,510
1926 . .	5,886	1,330
1927 . .	2,799	6,856
1928 . .	14,416	13
1929 . .	24,285	..
1930 . .	22,210	4,928
1931 . .	15,237	3,049

TABLE 18. *Imports of Principal Fertilizers into Ceylon*, 1925–31

(*metric tons*)

	S. ammonia	*N. soda*	*Phos. rock*	*Super-phos.*	*B. slag*	*Guano*	*Bone-products*	*Potash salts*
1925	6,783	2,948	6,604	3,821	2,900	9,447	16,304	13,540
1926	8,884	5,373	10,719	5,100	3,188	9,618	19,172	15,193
1927	13,059	6,393	13,411	5,890	3,300	10,932	17,094	16,040
1928	14,017	2,851	9,652	5,616	3,176	9,863	14,130	15,372
1929	16,708	5,066	13,901*	5,591	2,328	8,788	14,732	13,694
1930	16,387	3,715	53	5,517	1,951	7,608	12,985	12,532
1931	12,797	1,625	8,384	4,335	1,504	4,475	13,304	10,063

* Probably includes a small quantity shipped to India.

tion which, it should be remarked, amounted to about 80,000 tons in 1929 and about 56,000 tons in 1931.

During the past few years there has been a marked increase in the demand for fertilizers in Northern and Southern Rhodesia, territories which are not included in the statistics of the Union of South Africa, and other countries where the demand is developing are Palestine, Cyprus, and the West Indies. It is very probable that the rapid increase in agriculture, and more particularly in citrus culture, in Palestine will lead to steadily increasing fertilizer consumption, and force is lent to this contention from the fact that experimental work is being actively conducted to demonstrate the requirements of crops and the improved results that can be obtained from the use of fertilizers.

In conclusion, it may be predicted with confidence that many of the Dominions and territories of the Empire are only on the threshold of their possibilities in the use of fertilizers; the developments in Empire fertilizer-consumption in the post-War period, of which perhaps Australia and New Zealand provide the most striking examples, are remarkable, but with the extension of educational experimental work, which is now being so actively undertaken in all parts of the British Empire, many further remarkable developments may be anticipated as soon as the world economic crisis shall have spent itself.

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STUDIES ON SUGAR-CANE AND SUGAR-CANE SOILS

Pt. I. THE IMMEDIATE AND RESIDUAL EFFECTS OF LIME ON CROP-YIELD

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Introduction

General.—During the past six years a comprehensive series of field experiments with manures has been carried out in Trinidad. The general aim of these experiments has been to test, under Trinidad conditions, the manurial practices in vogue for sugar-cane in other countries with more highly developed systems of agriculture, and to investigate certain manurial problems which appear to have been previously overlooked.

The original field experiments of this series were carried out on one of the sugar plantations. Since then, the experiments have spread to practically every plantation of this kind in the island. Through the co-operation of their field officers, it has been feasible, with a limited research and controlling organization, to pursue the investigations on a very large scale, to work on a number of different problems at the same time, and to test the general value of any one set of results by the replication of similar experiments on different areas.

With very few exceptions the design of the experiments has been based on the 'Latin square' or 'randomized block' lay-out of Fisher [1]. In certain cases, on the more highly organized plantations, very complex designs have been used. In this manner it has been possible not only to raise the standard of manurial practice in Trinidad, but also to secure information of scientific value.

The majority of the investigations are still under way, but the work has now reached a stage when the results obtained can profitably be reviewed.

Crop-quality in relation to yield of sugar.—Manurial treatment may not only affect the yield of sugar-cane, but also the composition of the cane-juice. The total *weight of sugar to the acre in the field* is dependent on the yield of cane and the amount of sucrose in the cane. On the other hand, *the yield of available sugar*, i.e. sugar which can actually be extracted from the cane in the factory, and prepared for the market, is to some extent controlled by the proportion of sucrose to other soluble solids in the extracted juice. Due consideration has been given to these points in the general scheme of research.

Classification of the main lines of work.—Problems relating to the effects of manurial treatment on yield and quality of sugar-cane may be classified under three headings:

(1) The Immediate and Residual Effects of Lime.
(2) The Immediate and Residual Effects of Organic and Inorganic Manures.
(3) The Effects of Manurial Treatment on Ratoon-Canes.

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The first two headings concern those treatments which are applied to plant-canes, but which also influence the subsequent ratoon crops. The third heading concerns treatments specifically associated with ratoon-canes.

In this paper the immediate and residual effects of lime on the field of sugar-cane are discussed. The other two main lines of work will be dealt with subsequently.

Plant- and ratoon-canes.—When an area is replanted in sugar-cane the first crop harvested is known as the 'plant-cane' crop. In Trinidad, canes planted in the wet season are reaped when approximately 18 months old. The canes are cut flush with the soil and allowed to spring again, giving rise to 'ratoon'-canes, which are reaped when about 13 months old. Seedling canes are usually allowed to ratoon twice. In these circumstances three crops of cane are harvested in four years. On the more fertile soils, where planting in the dry season is feasible, the plant-canes may be reaped after 12 months' growth. Such plants are termed 'crop' plants. Hardy varieties of cane, such as Uba, may be allowed to ratoon many times. Replanting occurs when it ceases to be economical to continue ratooning.

THE IMMEDIATE AND RESIDUAL EFFECTS OF LIME

In all the experiments described in this paper the dressing of lime was applied immediately before replanting the area in sugar-cane. No lime was applied to the ratoon-canes.

I. *General Effect of Lime on Yield of Plant and Ratoon-Canes*

(*a*) *Unflocculated, Acid Soils*

An attempt was made to place the results obtained in different areas on a comparable basis by applying to each area dressings of lime equal in amount to its lime-requirement. The method used in the measurement of lime-requirement is discussed in a note at the end of this paper. Sugar-cane grown on typical unflocculated, acid soils responds generously to this liming treatment. Characteristic results obtained on heavy and light soils are recorded in Table 1.

Expts. I, II, and III were laid down on heavy clay soils of pH value 5·6 to 6·2. Expts. IV and V were laid down on light loam soils of pH value 5·4 to 6·7.

In Expt. I all plots were given an ample basal dressing of a complete artificial manure, both as plant-canes and first ratoons. In Expts. II, IV, and V all plots received a basal dressing of 20 tons of pen manure as plant-canes. No manurial treatment was applied to the ratoons. In Expt. III no dressings of organic or inorganic manure were given either to the plant- or ratoon-canes. Expt. V differs from the others in that the plant-canes were subject to severe and prolonged attacks of an insect pest.

In all five experiments the immediate and first residual increments might be due to chance less than once in 100 times.

It would be unwise to speculate too freely on the basis of the results

TABLE 1. *Immediate and First Residual Effect on Yield of Cane of Liming to the Lime-Requirement*

Unflocculated, Acid Soils

Seedling canes
Lay-out: Randomized blocks or Latin squares

Expt.	Limestone applied per acre	Yield		Increment in Yield			
		Plant-canes	First ratoons	Plant-canes	First ratoons	Plant-canes	First ratoons
		tons cane per acre		tons cane per acre		per cent.	
I	10 tons	36·05	42·26	6·15	5·74	20·6	15·7
	None	29·90	36·52				
II	10 tons	43·40	26·70	6·82	7·47	18·6	38·8
	None	36·58	19·23				
III	10 tons	37·93	25·08	6·96	11·01	22·5	78·3
	None	30·97	14·07				
IV	4 tons	19·20	23·90	5·78	7·81	43·1	48·5
	None	13·42	16·09				
V	4 tons	21·91	21·61	10·08	7·73	85·2	55·7
	None	11·83	13·88				
	Average	..	..	7·16	7·95	38·0	47·4

of five experiments, but the data in Table 1, when coupled with general experience, suggest the following deductions for unflocculated, acid soils:

(i) By liming to the lime-requirement, equally good results can be obtained on light and heavy soils.

(ii) On the average, the residual effect of lime on the first ratoon-canes, when measured as tons of cane to the acre, is as large as the immediate effect on the plant-cane crop.

(iii) The absolute increment in yield of *plant-canes*, due to liming to the lime-requirement, does not appear to be greatly influenced by the nature of the basal manurial treatment except in special circumstances, or unless untoward conditions obtain, as in Expt. V. It is probable that the intensive preparatory cultivation given to the soil, shortly before replanting, can in general render available a supply of soil nutrients in amount sufficient to mask any differential effects that might otherwise become evident.

The proportionate increment in yield of plant-canes, however, does appear to depend on other factors. Among these factors soil type appears to be important.

(iv) The increment in yield of *first ratoon-canes*, due to the residual effect of lime, may be more dependent on the basal manurial treatment than that of plant-canes. By far the largest residual effect on the heavy soils (Table 1) occurred in Expt. III, in which neither the plant- nor first ratoon-canes received a basal dressing of manure. The smallest effect on the heavy soils was obtained in Expt. I, in which both crops were given a complete dressing of artificials. An intermediate effect was obtained in Expt. II, which received a basal treatment only as plant-canes. This deduction would postulate the existence of an interaction

between the lime and the basal manurial treatment, and there is reason to believe that such an interaction can obtain. Field experiments in Trinidad indicate that the residual effect of preparatory intensive cultivation, before replanting, on the yield of first ratoon-canes is very small. The masking action of cultivation would therefore presumably not be in operation for the ratoon-canes.

Little is known at present with regard to the number of successive crops which benefit to the extent recorded in Table 1. The effect of lime undoubtedly extends to the second-ratoon crop, for in all five experiments the second ratoons on the unlimed plots gave a very poor 'spring' in comparison with those on the limed plots. Under Trinidad conditions it appears that the presence of adequate lime in the soil is a primary factor in determining the number of crops which can be reaped with advantage without replanting. This is a point of economic importance, for the average cost of one ton of ratoon-canes is less than one-third that of a ton of plant-canes.

Slaked lime versus *ground limestone*.—On the clay soils of Trinidad the effect of ground limestone appears to be somewhat superior to that of slaked lime [2]. Under tropical conditions it is very difficult to prevent slaked lime clotting into small lumps. This hinders its dispersion throughout the soil.

Fineness of division of limestone.—Experiments have been laid down to compare the effects of samples of limestone of varying degrees of fineness, but sufficient information is not yet to hand to make a detailed comparison. It appears, however, that it is preferable to use limestone of which 70 per cent. passes through a 100-mesh sieve.

Results obtained elsewhere.—Sugar-cane, grown on acid soils, responds to treatment with lime in Queensland as generously as in Trinidad. The data of Kerr and Barke [3] indicate that when the dressing of lime applied to the plant-canes is small, the yield of first ratoon-canes on limed plots is not greatly superior to the yield on unlimed plots. When the plant-canes are more heavily limed, however, the first residual effect of lime is equal to its immediate effect.

In British Guiana it is customary to regenerate sugar-cane soils by flooding. The advantages which there result from this procedure are unquestionable. Williams and Follett-Smith [4] find that sugar-cane responds to liming on unflooded areas, but not on similar areas of flooded soil. Their results indicate that there is little to choose between the effects of ground limestone and slaked lime on the yield of plant-canes.

In the Philippines [5] and Cuba [6], increments in yield of plant-canes of 24 per cent. and 14 per cent. respectively are reported to result from dressings of lime.

According to Arrhenius [7] the yield of sugar-cane in Java, on the whole, decreases with increasing soil acidity. The few liming experiments laid down in that country have given positive results.

Only incidental mention is made of lime as a manure for sugar-cane in the literature published from Hawaii. There appears to be no record of any liming experiments on sugar-cane in South Africa.

(*b*) *Exhausted Soils*

Field experience in Trinidad indicates that sugar-cane responds more slowly to liming on soils which have been exhausted by wasteful methods of agriculture than on soils which are merely unflocculated through lack of lime. The results of a liming experiment on an exhausted soil are recorded in Table 2.

TABLE 2. *Immediate and Residual Effect of Lime on Yield of Cane-exhausted Soil*

Cane variety: B. 156
Lay-out: Three 8×8 Latin squares

Experiment VI

Limestone applied per acre	*Yield (tons cane per acre)*			
	Plants	*1st Ratoons*	*2nd Ratoons*	*Total*
16 tons . . .	36·26	40·25	19·56	96·07
None . . .	34·58	35·70	14·07	84·35
Increment in Yield:				
Tons cane . .	1·68±0·69	4·55±0·77	5·49±0·62	11·72
Per cent. . . .	4·9	12·7	39·0	13·9

The area of this experiment was previously in the hands of peasants, who practised a type of 'shifting' cultivation. A crop of sugar-cane was grown, the land abandoned to bush, the bush burned, and sugar-cane replanted. This primitive type of rotation had been repeated many times, and had caused marked exhaustion of the soil. When the experiment was laid down the soil appeared almost devoid of chemical nutrients, and its physical condition was extremely poor.

The soil of the experimental area contained 22 per cent. clay, 27 per cent. silt, and 37 per cent. fine sand. Its pH value was 6·5. Its lime-requirement was 16 tons of ground limestone to the acre, a rather high value in view of its mechanical composition and pH value. The area was intensively tilled before planting. The plant-canes received an average basal dressing of 10 tons of pen manure to the acre. The first and second ratoons were each given 3 cwt. of sulphate of ammonia.

The immediate increment for plant-canes, and the residual increments for first and second ratoon-canes, are all definitely significant.

The yield data in Table 2 have two main features of interest: (i) Although a very heavy dressing of lime was applied, the increment in yield of plant-canes is very small in comparison with the results recorded for the unflocculated soils in Table 1.

(ii) The residual effect of lime on the yield of the ratoon-canes is very much greater than its immediate effect on the plant-canes. The increment in yield of 5·49 tons of second ratoon-canes approaches the average immediate increment of 7 tons for plant-canes on typical unflocculated soils. The primitive methods of agriculture previously practised on the experimental area appear to have rendered the soil at first relatively inert to lime, but in the course of time the action of lime on the soil, as measured by the yield data, seems to be attaining normal proportions.

The first ratoon-canes in Expt. VI gave an abnormally high yield in view of the basal manurial treatments applied. It appears in this case that the benefits of intensive preparatory cultivation extended to the first-ratoon crop, an unusual occurrence. On the other hand, the second ratoon-canes gave a very low yield, although the basal treatments they received were identical with those given to the first ratoons.

In another experiment laid down in Trinidad on a somewhat similar soil, liming resulted in an increase in yield of 6 per cent. for plant-canes and 12 per cent. for the first ratoon crop [2].

In Porto Rico, Dominguez [8] has found that the absolute and proportional effect of lime increases with succeeding crops on a poorly drained, stiff clay soil of low productivity. Average values for his figures are reproduced below. Slaked lime was applied at the rate of one ton to the acre.

Crop after liming	*First*	*Second*	*Third*	*Fourth*
Gain due to liming				
Tons cane . . .	0·84	2·80	3·19	7·50
Per cent. . . .	3	12	35	95

II. *Effect of Amount of Lime on Yield of Cane in the Presence and Absence of Sulphate of Ammonia*

In Table 3 are recorded the effects of increasing dressings of lime on the yield of a complete crop series of plant, first and second ratoon-canes, of two varieties.

TABLE 3. *Effect of Increasing Dressings of Lime on Yield of Cane*

L.R. = calculated lime-requirement
= 16 tons limestone to the acre in Expt. VII
= 20 tons limestone to the acre in Expt. VIII
Lay-out: three 8×8 Latin squares

	Expt. VII. Cane Variety B. 156			*Expt. VIII. Cane Variety BH 10/12*		
	Yield (tons cane to the acre)			*Yield (tons cane to the acre)*		
Treatment with limestone	(*a*) *Plants** (*1929–31*)	(*b*) *1st Ratoons*† (*1931–2*)	(*c*) *2nd Ratoons*† (*1932–3*)	(*a*) *Plants** (*1929–31*)	(*b*) *1st Ratoons*‡ (*1931–2*)	(*c*) *2nd Ratoons*‡ (*1932–3*)
None	34·58	35·70	14·07	36·03	22·12	10·93
½ L.R.	35·88	39·25	17·82	41·74	24·65	14·23
L.R.	36·26	40·25	19·56	42·77	24·09	14·69
1½ L.R.	36·98	39·00	18·38	43·44	25·27	15·32

* Received a basal dressing of pen manure.
† Received a basal dressing of sulphate of ammonia.
‡ Received no basal manurial treatment.

Expt. VII was laid down on the area of degenerated soil described in the previous section. Expt. VIII was laid down on a raw clay soil of pH value 6·0. In both experiments there were 48 replicates of each of four liming treatments: (i) no lime, (ii) half lime-requirement, (iii) full lime-requirement, and (iv) 1½ lime-requirement. Each experiment included three 8×8 Latin squares, the individual liming treatments being repeated, both with and without pen manure, in each row and column. Each plot was one-tenth of an acre in area.

(*a*) *Effect of sulphate of ammonia on the form of the yield-curve.*—The yield-curves for the data in Table 3 fall into two classes according as the crop did or did not receive a basal dressing of sulphate of ammonia.

The curves for the crops without sulphate of ammonia (the plant-canes in Expt. VII and the plant-canes, first and second ratoons, in Expt. VIII) *are curves of diminishing returns.* The increment due to liming for each of these four crops is statistically significant. The successive increments become smaller as the dressing of lime increases, but there is no evidence of an ultimate fall in yield even with the heaviest liming treatment.

The irregularities in yield of the first ratoon-canes in Expt. VIII arise from this experiment being laid down on an undulating area, and from the canes on the hill-tops having suffered severely from drought at an early stage of growth.

The curves for the crops which received a basal dressing of sulphate of ammonia (the first and second ratoon-canes in Expt. VII) *appear to rise to a maximum and then fall as the dressing of lime increases.* In both cases the initial increments are definitely significant. The subsequent falls, from the full to 1½ times the lime requirement, might be due to chance about once in 20 times.

The two yield-curves may be represented by equations of the form:

$$Y = A + B\xi_1 + C\xi_2,$$

where A is the mean yield for all plots, and B and C are constants.

$$\xi_1 = x - \bar{x}, \quad \xi_2 = \xi_1^2 - \frac{n^2-1}{12}, \quad n = 4.$$

The values 1, 2, 3, and 4 for x correspond to 0, ½ L.R., L.R., and 1½ L.R. respectively.

A, B, and C possess the following values:

Expt. VII	A	B	C	$-\frac{B}{2C}$
1st Ratoons	38·55	1·090±0·0043	−1·200±0·0048	0·453±0·0393 (≡ 0·98 L.R.)
2nd Ratoons	17·46	1·467±0·0131	−1·232±0·0147	0·595±0·009 (≡ 1·04 L.R.)

As the standard errors of B and C were found from 48 degrees of freedom, both constants are undoubtedly significant. *The rise and subsequent fall in yield, as the dressing of lime increases, of the first and second ratoon-canes which received a basal dressing of sulphate of ammonia, may therefore be judged as definitely established.* This appears to be the first occasion, at any rate for sugar-cane, on which over-liming has been shown to cause a significant fall in yield [9].

The dressing of lime which gives maximum yield can be calculated. For the first ratoon-canes, at the maximum point of the curve,

$$x - \bar{x} = -\frac{B}{2C} = 0{\cdot}453.$$

As $\bar{x} = 2{\cdot}5$, $x = 2{\cdot}953$. Converting this value for x into terms of the lime-requirement, the maximum yield corresponds to $\frac{1}{2}(2{\cdot}953 - 1)$ L.R.

or 0·98 times the calculated lime-requirement. The maximum yield for the second ratoon-canes occurs at 1·04 times the lime-requirement. In both cases the standard deviation of $-\frac{B}{2C}$ is very small.

The weather was abnormally wet throughout the life of the first ratoon-canes. Normal conditions, i.e. a wet season followed by a dry season, prevailed during the life of the second ratoons. Nevertheless a rise and fall in yield of cane was obtained in both cases. The position of the maximum point on the curve, with respect to the amount of lime applied, therefore seems to be largely independent of the amount and distribution of the rainfall in these two years. It will be seen later, however, that both the form of the corresponding curve for the sucrose-content of the cane, and the optimum dressing of lime for maximum sucrose-content, appear to be influenced by this variation in weather conditions.

The ground limestone used in these experiments contained 0·029 per cent. of manganese as carbonate. Allison [10] and others have demonstrated that small amounts of manganese stimulate the growth of sugar-cane in the presence of excessive lime. It is probable that the diminution in yield of ratoon-canes, through over-liming, might have been even more emphasized if the limestone had not contained manganese.

(*b*) *The interaction of lime with sulphate of ammonia.*—The existence of curves of two such forms suggests that an interaction of an unusual kind occurs between the lime and sulphate of ammonia. To test the significance of this interaction each row of plots in one Latin square of Expt. VII was divided into three strips. The strips ran the whole length of the rows. To one strip in each of the eight rows a dressing of 3 cwt. per acre of sulphate of ammonia was applied. The position of this strip in each row was determined at random. This type of lay-out has the merit of determining interactions with a considerable degree of accuracy [11].

The yield-data obtained are recorded in Table 4 and in Fig. 1.

TABLE 4. *The Interaction of Lime with Sulphate of Ammonia in Relation to Yield of Cane*

L.R. = calculated lime-requirement
Ratoon-canes: variety B. 156
Yield of cane (tons per acre)

Sub-treatment with sulphate of ammonia	*Dressing of limestone*			
	None	½ *L.R.*	*L.R.*	1½ *L.R.*
3 cwt. per acre .	40·61	42·02	45·69	41·78
None . . .	33·25	37·86	37·53	37·61

In Table 4 the significant difference between two mean yields for a sub-treatment is 1·99 tons cane for $P=0{\cdot}01$, and 1·51 tons cane for $P=0{\cdot}05$.

In the presence of sulphate of ammonia the yield-curve rises and falls, as the dose of lime increases, in the manner anticipated. Both rise and fall might be due to chance less than once in 100 times. In this experiment the yield obtained with the maximum dressing of lime is actually smaller than that given by half the lime-requirement.

Expressing the curve in the form $Y = A + B\xi_1 + C\xi_2$, $A = 42{\cdot}53$, $B = 0{\cdot}718 \pm 0{\cdot}246$, and $C = -1{\cdot}33 \pm 0{\cdot}275$. As the number of replicates of each treatment is 16, both B and C are definitely significant. The value of $-\frac{B}{2C}$ is $+0{\cdot}27 \pm 0{\cdot}108$. The maximum yield therefore occurs at 0·89 times the calculated lime-requirement.

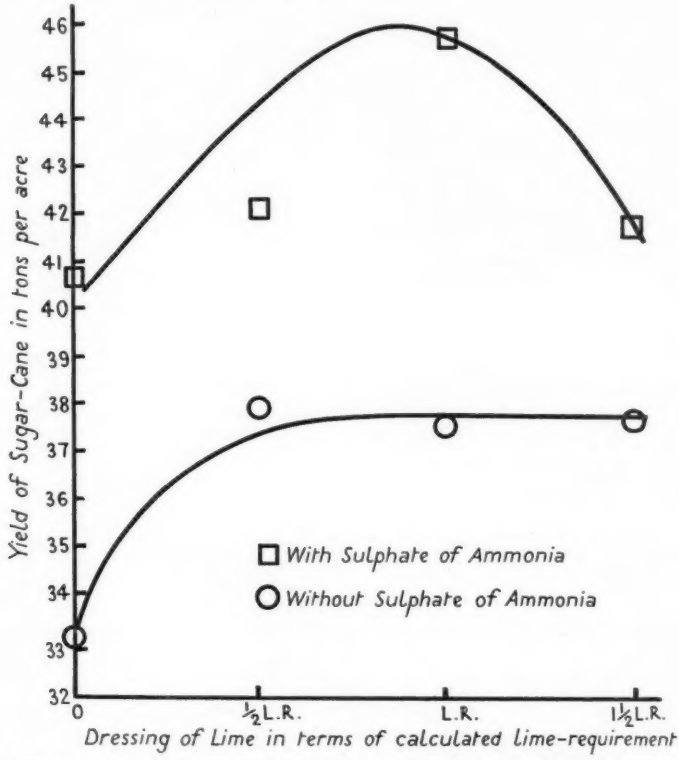

FIG. 1. Effect of Increasing Dressings of Lime on yield of Sugar-cane in the presence and absence of Sulphate of Ammonia.

In the absence of sulphate of ammonia, the yield reaches a maximum in the region of half the lime-requirement. Any variations in yield beyond this point are definitely not significant.

The portion of the analysis of variance for the data in Table 4, which is relevant to the interaction, is set out below:

Due to	*D.F.*	*S.S.*	*Mean square*	$\frac{1}{2}\log_e$
N × lime	3	4,014	1338·0	1·297
N × main treatments × rows .	49 } 105	27,448	560·2 } 530·3	0·834
Sub-plot duplicates . .	56 }	28,238	504·2 }	

For $n_1 = 3$ and $n_2 = \infty$, $z = 0{\cdot}479$ when $P = 0{\cdot}05$. For the interaction of nitrogen with lime, $z = 0{\cdot}463$. The interaction therefore lies on the border-line of significance.

A similar rise and fall in yield of cane can result from applying increasing dressings of sulphate of ammonia on calcareous soils, but not on acid, lime-deficient soils (Table 5).

TABLE 5. *Effect of Increasing Dressings of Sulphate of Ammonia on Yield of Plant-canes* (*Calcareous and Non-calcareous Soils*)

S/A = Sulphate of ammonia
Lay-out: 12 randomized blocks of 4 treatments

	Expt. IX. Calcareous marl soil		*Expt. X. Acid clay soil*	
	Cane variety B.H. 10 (12)		*Cane variety Uba*	
Dressing of S/A per acre	*Yield*	*Gain in yield*	*Yield*	*Gain in yield*
	Tons cane per acre		*Tons cane per acre*	
None	31·40	..	43·11	..
5 cwt.	34·75	3·35	50·96	7·85
10 cwt.	37·50	6·10	50·46	7·35
20 cwt.	30·79	−0·61	50·46	7·35

The significant difference between any two mean yields for the experiment on the calcareous soil is 5·01 tons of cane for $P = 0{\cdot}01$. The rise and subsequent fall in yield might therefore be due to chance less than once in 100 times. The yield on the plots which received one ton of sulphate of ammonia is actually smaller than on the untreated plots. The calcareous soil contained 0·09 per cent. of manganese [10].

The increment in yield of over 7 tons of cane to the acre on the acid clay soil, due to treatment with sulphate of ammonia, is definitely significant. Maximum yield is attained before the dressing exceeds 5 cwt. No fall in yield results from applications of larger amounts of nitrogen. Expts. IX and X were identical in all details other than soil type and variety of cane. The yield-curves for the two experiments are compared in Fig. 2.

Other similar experiments have been carried out with heavy applications of sulphate of ammonia on soils deficient in lime. In every case the yields followed the law of diminishing returns. *Only on soils containing free calcium carbonate has an ultimate fall in yield been found to occur.*

In British Guiana, Williams and Follett-Smith [4] record two examples of a similar interaction of lime with nitrogen in relation to yield of sugar-cane. In their experiments the effect of increasing dressings of lime and of nitrogen were measured at the same time. In both cases the interaction was found to be significant. The variety of sugar-cane with which they worked was D. 625.

There can be little doubt, therefore, that *the increment in yield due to liming, in the presence of sulphate of ammonia, at first rises but can ultimately fall as the dressing of lime is increased.* It is believed that an interaction of lime with nitrogen of this nature has not previously been suspected.

The data in Tables 4 and 5, and the yield-figures of Williams and Follett-Smith [4], further indicate that a depression in yield obtains with lime and sulphate of ammonia only when one of these manures is present in very large amount. On the exhausted soil of Trinidad it is necessary to apply limestone in amounts exceeding 16 tons to the acre before yield

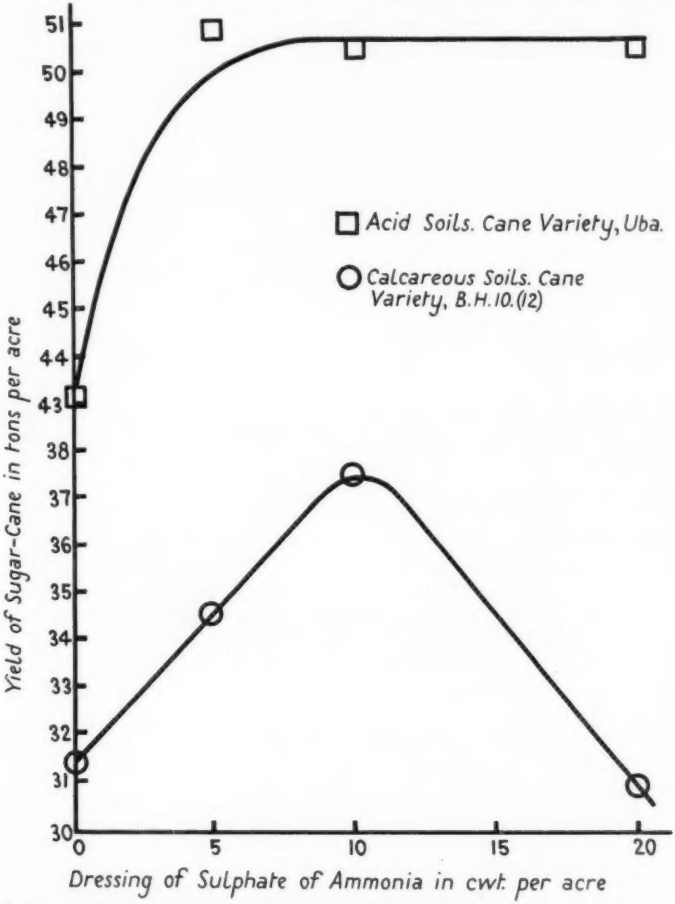

FIG. 2. Effect of Increasing Dressings of Sulphate of Ammonia on yield of Sugar-cane grown in Calcareous and Non-calcareous Soils.

is depressed in the presence of 3 cwt. of sulphate of ammonia. Alternatively, if only a small excess of lime is present, as in the calcareous soil, more than 10 cwt. of sulphate of ammonia to the acre are required. In British Guiana the depression first becomes evident when dressings of sulphate of ammonia exceeding 4 cwt. to the acre are applied with a basal dressing of 8 tons of limestone.

(*c*) *The effect of potash and phosphate on the interaction of lime with sulphate of ammonia.*—Experimental work in Trinidad has shown that a depression in yield, of the type which can obtain when sulphate of ammonia is applied in the presence of lime, is in general found to occur when the manurial treatment is unbalanced, and may be remedied by supplying the deficient element. The effect of potash, alone and in the presence of phosphate, on the interaction under discussion has therefore been investigated.

The preliminary studies were carried out on one of the Latin squares of the liming experiment laid down on the area of degenerated soil (Expt. VII). Each row of this square was divided into three strips, as in the previous case. A basal dressing of 3 cwt. of sulphate of ammonia to the acre was applied to all the strips. One strip in each row was given 2 cwt. of sulphate of potash to the acre. A second strip received 2 cwt. of potash and 1 cwt. of superphosphate. The third strip was given no additional treatment. The position of these sub-treatments in each row was decided at random. Subdivision of the rows into more than three strips was impracticable.

The data obtained are recorded in Table 6 and Fig. 3.

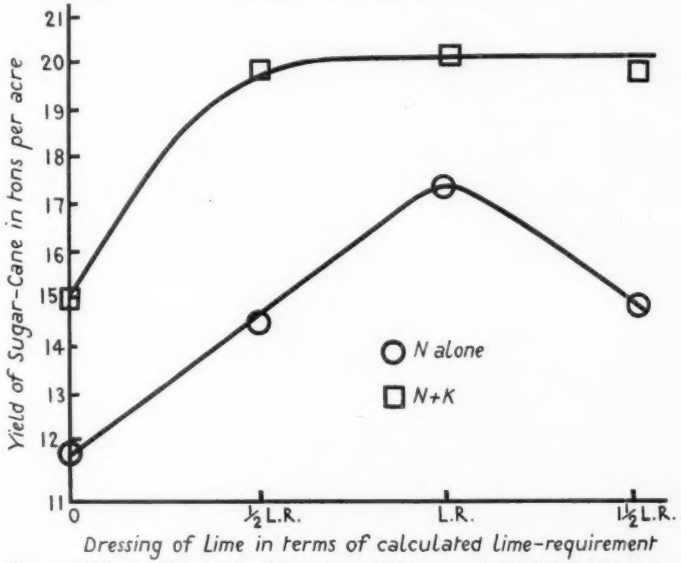

FIG. 3. Effect of Increasing Dressings of Lime on yield of Sugar-cane in presence of Sulphate of Ammonia alone and Sulphate of Ammonia plus Potash.

In each strip the rise in yield continues up to the full lime-requirement. *The position of the maximum point on the curve, with respect to the amount of lime applied, therefore does not appear to be affected by treatment with potash and phosphate.*

The significant difference between any two of the mean yields in a

TABLE 6. *Effect of Potash and Phosphate on the Interaction of Lime with Nitrogen*

L.R. = calculated lime-requirement
Ratoon-canes: variety B. 156
Yield of cane (tons per acre)

Sub-treatment	*Dressing of limestone*			
	None	½ *L.R.*	*L.R.*	1½ *L.R.*
N	11·92	14·71	17·73	15·13
NK	15·19	20·10	20·47	20·11
NKP	14·95	18·60	20·46	19·91

strip is 1·93 tons of cane for $P=0.05$ and 2·51 tons for $P=0.01$. The increment in yield due to application of the lime-requirement is therefore significant, irrespective of the nature of the sub-treatment. The fall in yield of 2·60 tons of cane, from the full to 1½ times the lime-requirement, when nitrogen alone is applied, might be due to chance less than once in 100 times. The corresponding falls in yield of 0·365 tons when potash is added, and 0·555 tons in the presence of potash and phosphate, are definitely not significant. The data in Table 6 suggest, therefore, *that the interaction of lime with sulphate of ammonia occurs in the absence of adequate potash.* Lack of phosphate does not appear to be associated with the ultimate fall in yield in this example.

Such a conclusion explains the fact that 3 cwt. of sulphate of ammonia can cause a significant depression in yield on the area of degenerated soil, whereas approximately 10 cwt. are needed on the calcareous soil. The data in Table 6 show that the degenerated soil is deficient in potash but not in phosphate. The response in yield to the former nutrient might be due to chance less than once in 100 times. On the other hand, the calcareous soil responds neither to potash nor phosphate in the presence of moderate dressings of sulphate of ammonia. The conclusion could also explain the absence of the interaction in the case of the plant-cane crops of Expts. VII and VIII. The basal dressing of pen manure contained available potash as well as available nitrogen.

Experiments of a more critical nature have been laid down to examine fully the circumstances which control the interaction.

When the yield curve, for the strips receiving nitrogen alone, is represented by the equation $Y = A+B\xi_1+C\xi_2$, the values of A, B, C, and $-\frac{B}{2C}$ are as follows:

Sub-treatment	A	B	C	$-\frac{B}{2C}$
N	14·874	1·264±0·146	−1·349±0·163	0·470±0·078 (≡0·98 L.R.)

B, C, and $+\frac{B}{2C}$ are definitely significant, P being less than 0·01 for each constant. The maximum yield in this experiment occurs at 0·98 times the lime-requirement.

III. *Note on the Method used for Measuring Lime-requirement*

The heaviest yields for a crop series of plant- and ratoon-canes in Trinidad are normally obtained on naturally calcareous soils. These soils, which for practical purposes can presumably be considered to be in equilibrium with calcium carbonate, have been found, on the average, to be 80 per cent. saturated with exchangeable calcium [12]. This finding has been used as the criterion in the measurement of lime-requirement, that is, lime-requirement has been calculated as the amount needed to raise the lime-status of the soil to the 80 per cent. level.

It has been shown elsewhere [9] that the optimum dressing of sulphate of ammonia for ratoon-canes in Trinidad is 3 cwt. to the acre. In the presence of this dressing maximum yields have been obtained in various experiments at the values 0·98, 1·04, 0·89, and 0·98 times the calculated lime-requirement. The near approximation of these values to unity is in part due to the very thorough preliminary sampling of the experimental area.

The laboratory technique used in Trinidad for determining lime-requirement has been criticized by Crowther and Basu [13] on the basis of results obtained by them in the examination of Woburn soils which differ very greatly in their general properties from the soils of Trinidad. The data of Crowther and Basu indicate that naturally calcareous soils would closely approach 100 per cent. saturation with exchangeable calcium in the field. So far as Trinidad soils are concerned, complete interaction of the soil with lime, which postulates an almost entire absence of the reverse reaction through hydrolysis, is unlikely on general principles.

The very close approximation of the actual value for lime-requirement, as determined by field experiments, to the calculated value, appears to confirm the validity of the method of measurement used in Trinidad.

Summary

(*a*) Plant- and ratoon-canes, grown on unflocculated, acid soils, benefit greatly by liming up to the lime-requirement of the soil.

(*b*) On soils exhausted through continued practice of a type of 'shifting' cultivation, the benefit derived from liming is at first very small, but it appears to attain normal proportions in the course of time.

(*c*) Sulphate of ammonia can significantly influence the effect of increasing doses of lime. In the absence of sulphate of ammonia the lime-yield curve follows the law of diminishing returns. In its presence, the curve rises to a maximum which is followed by a significant fall. The maximum point corresponds to a dressing of lime equal to the calculated lime-requirement.

The ultimate fall in yield appears to be caused by lack of balance in the manurial treatment, for it can become evident either when an excess of lime is applied in the presence of small dressings of sulphate of ammonia, or when an excess of sulphate of ammonia is applied in the presence of moderate amounts of lime. Further, the ultimate fall in yield ceases to obtain when the deficient element is applied.

The optimum dressing of lime for maximum yield does not appear to vary with weather conditions.

(*d*) Fluctuations in the quality of cane due to liming are unimportant in comparison with the accompanying increment in yield, unless conditions are very unusual. Maximum yield of sugar to the acre is consequently obtained by liming up to the lime requirement for maximum yield of cane.

(*e*) The field experiments described confirm the validity of the method used for measuring lime-requirement, which is based on the degree of unsaturation of the soil with exchangeable calcium.

Acknowledgements

Some of the experiments described in this paper include as many as 600 plots laid down on a randomized basis. The accurate harvesting of a single experiment of this nature may disorganize the routine operations of a section of a sugar-plantation for as long as three weeks during the busiest period of the year. The author therefore wishes to acknowledge his indebtedness to the staff of these plantations for their assistance and co-operation.

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